Mapping the Zone: Improving Flood Map Accuracy

David Maidment, Chair

Briefing for ASPRS Coastal Lidar Workshop

November 15, 2009

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Presentation Outline

- Overview of Committee Charge
- Review of Elevation for Floodplain mapping study
- Mapping the Zone Report Chapters
  - 1-3 Overview of flood mapping and terrain data
  - 4-5 Inland and Coastal flood mapping
- Overarching Findings

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Committee Charge: Tasks 1 & 2

1. Examine the current methods of constructing FEMA flood maps and the relationship between the methods used to conduct a flood map study (detailed study, limited detailed study, automated approximate analysis, or redelineation of existing hazard information), the accuracy of the predicted flood elevations, and the accuracy of predicted flood inundation boundaries.
2. Examine the economic impacts of inaccuracies in the flood elevations and floodplain delineations in relation to the risk class of the area being mapped (based on the value of development and number of inhabitants in the risk zone).

Committee Charge: Task 3

3. Investigate the impact that various study components (i.e., variables) have on the mapping of flood inundation boundaries:
   a. Riverine flooding
      - The accuracy of digital terrain information
      - Hydrologic uncertainties in determining the flood discharge
      - Hydraulic uncertainties in converting the discharge into a flood water surface elevation
   b. Coastal flooding
      - The accuracy of the digital terrain information
      - Uncertainties in the analysis of the coastal flood elevations
   c. Interconnected ponds (e.g., Florida)
      - The accuracy of the digital terrain information
      - Uncertainties in the analysis of flood elevations

Committee Charge: Tasks 4-6

4. Provide recommendations for cost-effective improvements to FEMA's flood study and mapping methods.
5. Provide recommendations as to how the accuracy of FEMA flood maps can be better quantified and communicated.
6. Provide recommendations on how to better manage the geospatial data produced by FEMA flood map studies and integrate these data with other national hydrologic information systems.

Committee Membership

David Maidment, Chair, University of Texas
David Brookshire, University of New Mexico
J. William Brown, City of Greenville, South Carolina
John Dorman, State of North Carolina
Gerald Galloway, University of Maryland
Bisher Imam, University of California, Irvine
Wendy Lathrop, Cadastral Consulting
David Maune, Dewberry
Burrell Montz, Binghamton University
Spencer Rogers, North Carolina Sea Grant
Karen Schuckman, Pennsylvania State University
Y. Peter Sheng, University of Florida
Juan Valdes, University of Arizona

Practitioners
Academics
Geodesy
Hydrology
Coastal
Economics
Risk

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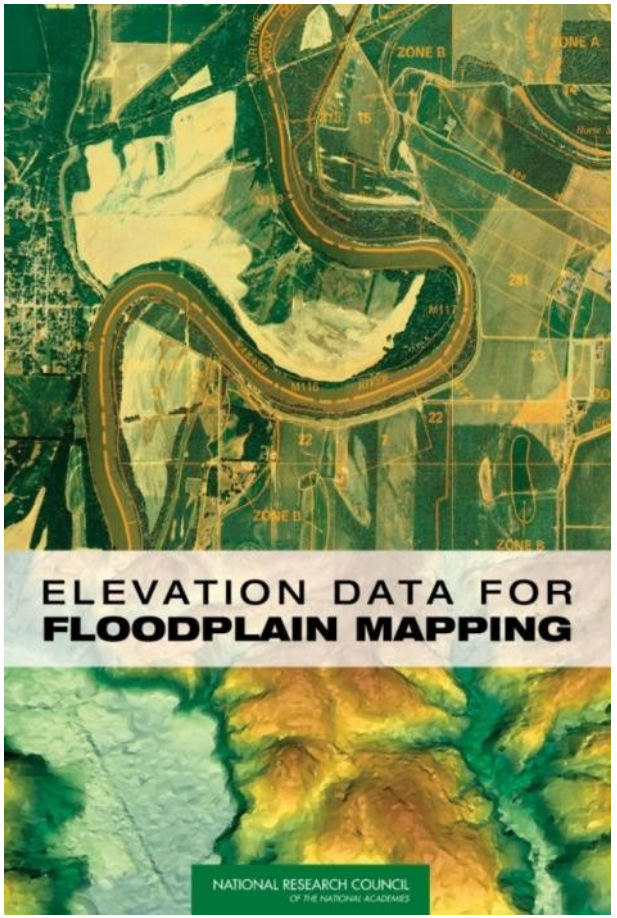
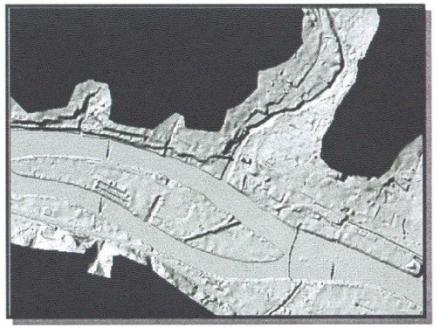
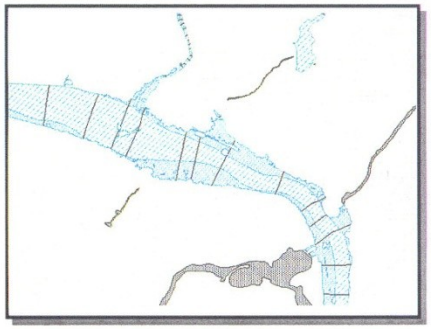
Previous NRC Studies:
Flood Map Technologies (2007)

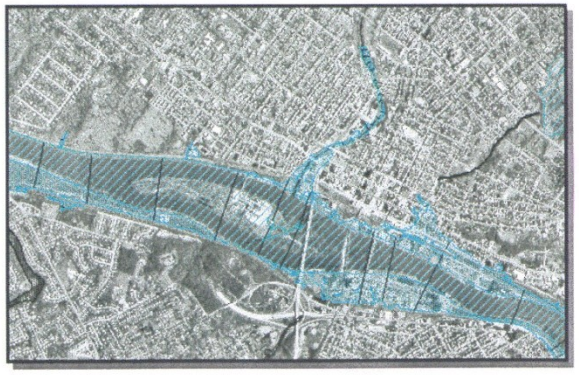
- An examination of the accuracy of flood base map input data
  - 2D imagery and planimetrics
  - 3D elevation
- Prompted by issues raised by Senate Appropriations Committee staff



DFIRM Components

‘Base map information’

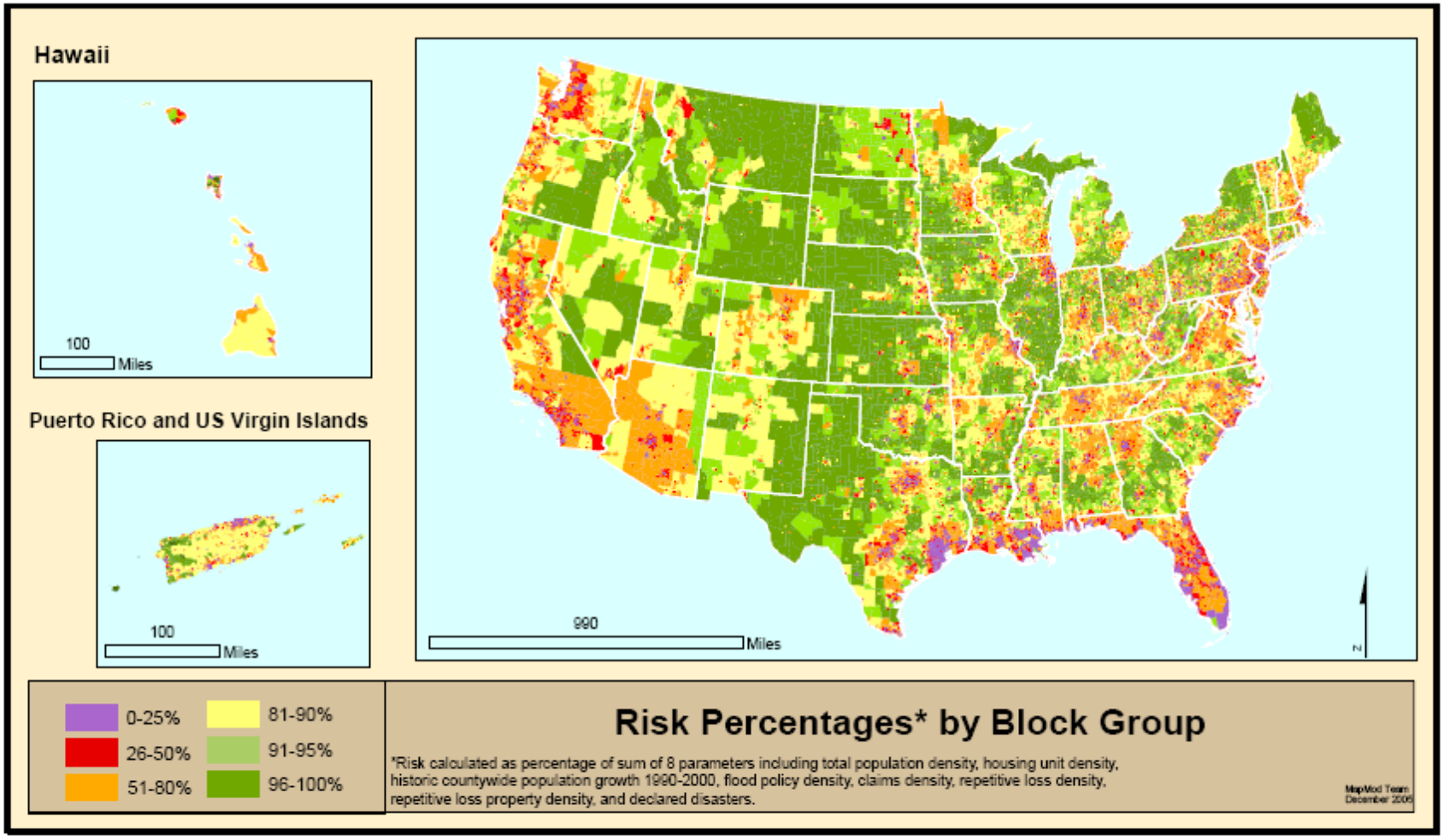
Imagery +  **Elevation** +  **Flood Data***

=  **DFIRM**

This study addressed the technologies producing Imagery and Elevation data components of the DFIRM

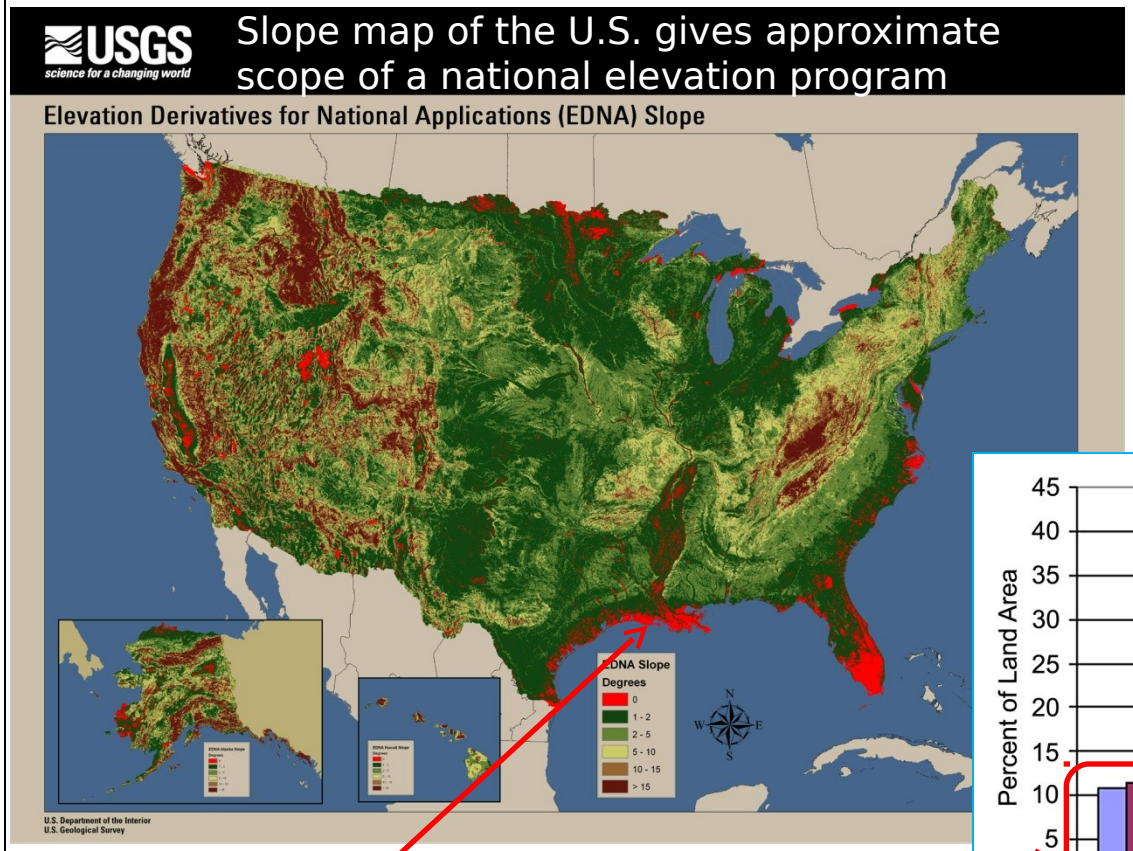
**New, 2-year NRC study sponsored by FEMA will look at Flood Map Accuracy and include analysis of Flood Data component of the DFIRM*

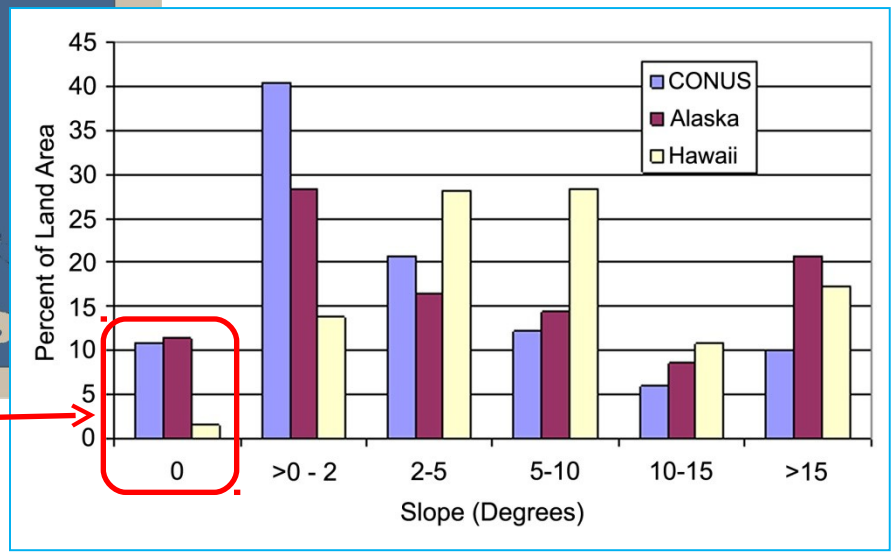
Where is Risk the Greatest?



Scott Edelman (Watershed Concepts)

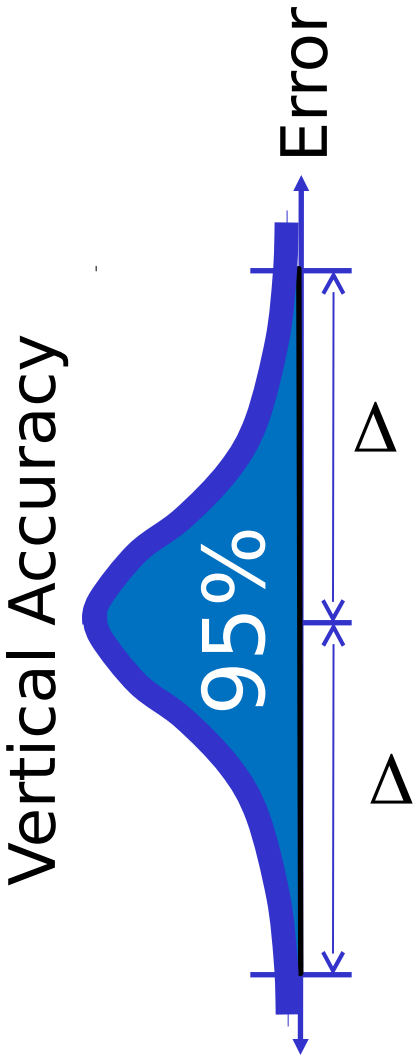
National Elevation Dataset





11% of the continental US and Alaska has zero slope in the current National Elevation Dataset, much of which is in high-risk, coastal flooding areas.

Why LIDAR?



FEMA Flood Map Accuracy Standards

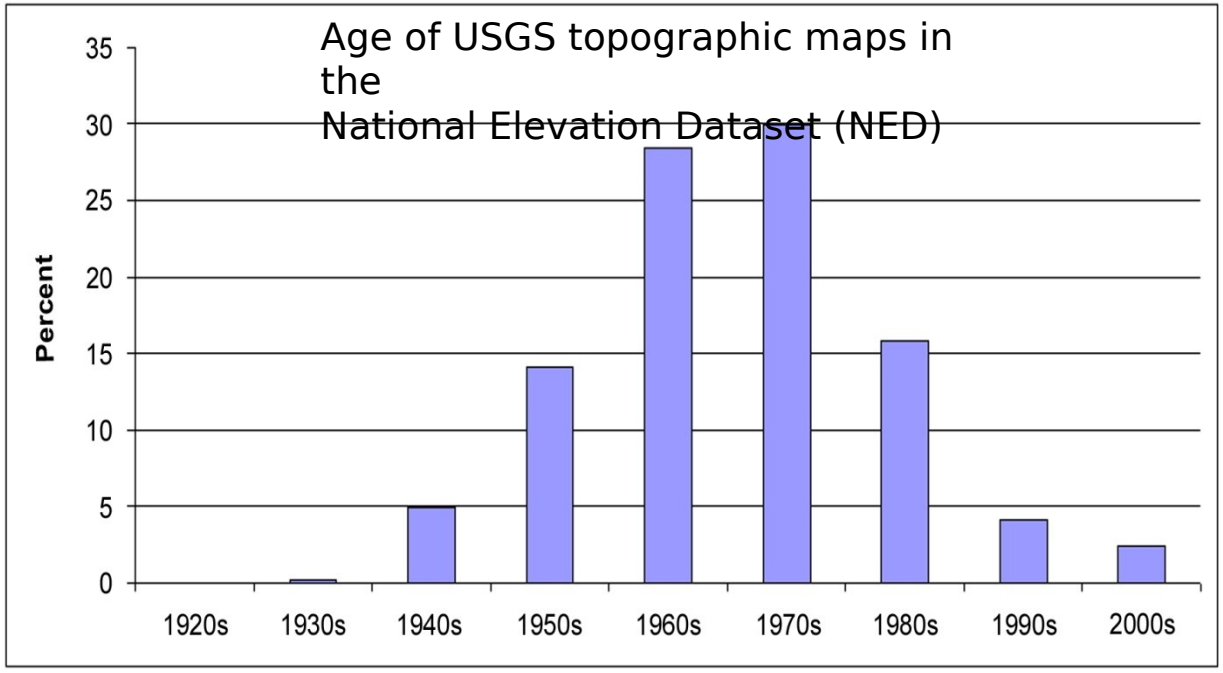
Flat Terrain: $\Delta = 1.2$ ft

Rolling to Hilly Terrain: $\Delta = 2.4$ ft

National Elevation Dataset:

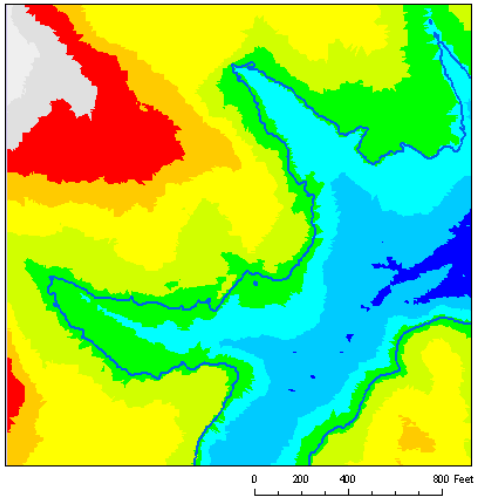
Compared to survey benchmarks: $\Delta = 15$ ft

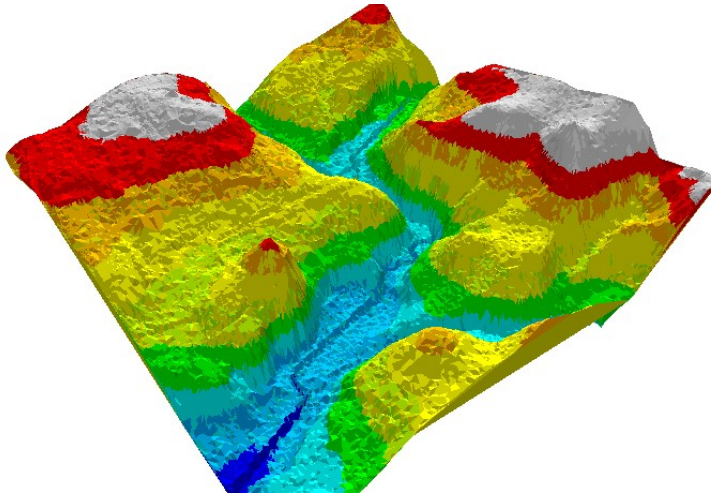
Elevation for the Nation



- Terrain data in USGS topographic maps are on average 35 years old and flood mapping requires data that are either collected or considered for updating within the last 7 years.

Base Elevation Data in Detail—Light Detection and Ranging (lidar)





Current 2-D Determinations: Lidar data enables the most accurate delineation of floodplains consistent with current methodology for flood risk determinations based on horizontal location of a structure relative to Special Flood Hazard Areas depicted on flat Flood Insurance Rate Maps.

Future 3-D Determinations: Lidar data would also enable accurate flood risk determinations based on the vertical comparison of a structure's lowest adjacent grade (LAG) relative to the Base Flood Elevation (BFE)

Conclusions and Recommendations

Rational flood management for the nation requires a three-dimensional view, quantifying both the variable Base Flood Elevations (BFEs) throughout the floodplain (vertical) and the areal extent (horizontal) of the 1% annual chance (100-year) flood where the BFEs intersect the terrain surface as depicted by digital elevation models.

To support the NFIP, analyzing these features in three-dimensions requires high-accuracy base map elevation data.

Existing elevation data are about 1/10 as accurate and about 5 times older than needed for the flood mapping task.

SUMMARY: A new digital mapping program for this land surface elevation is needed, which the committee has termed *Elevation for the Nation*

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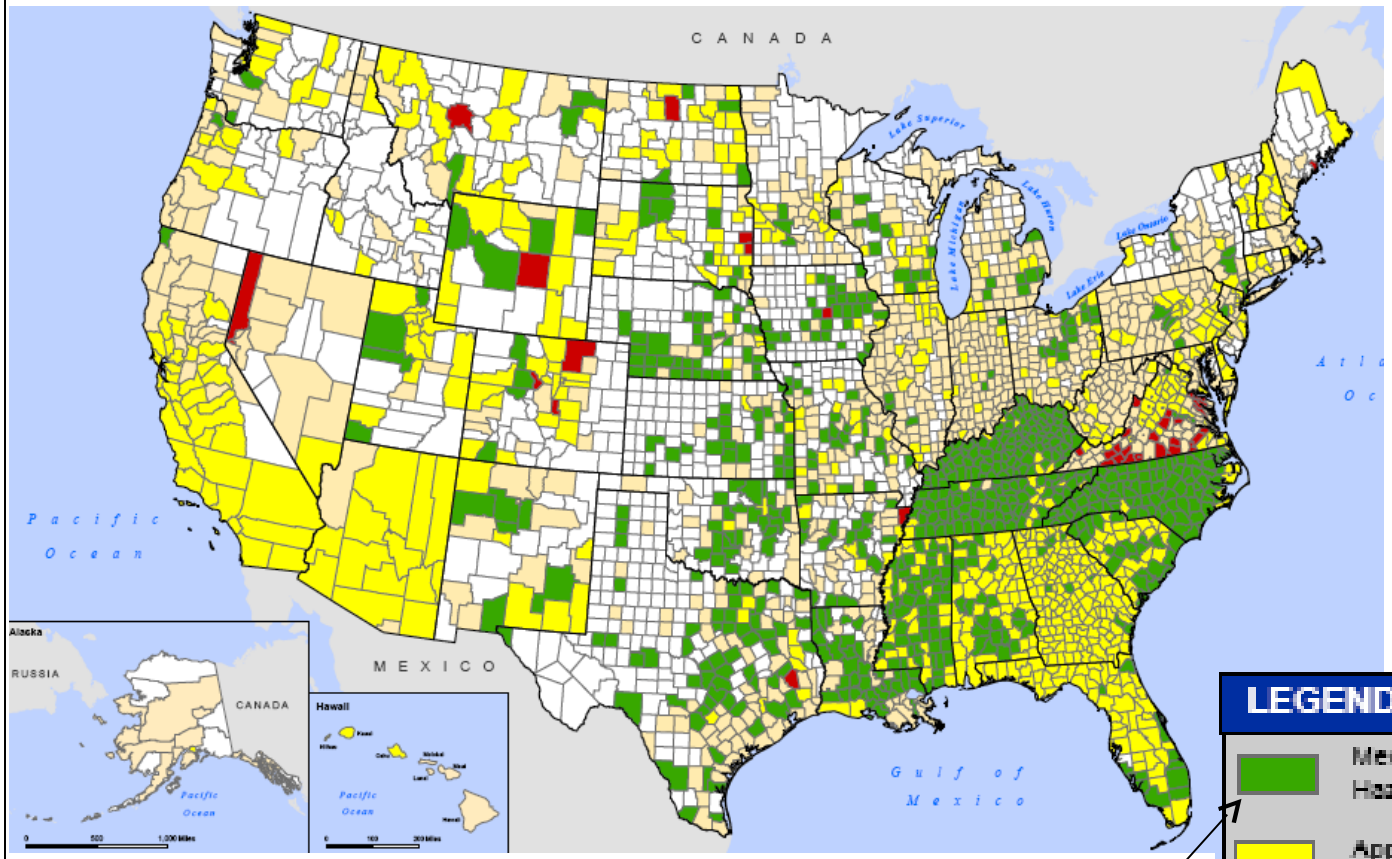
Status of National Flood Hazard Data Quality Standards as of March 31, 2008



Adjusted goal: 92% of population and 65% of land area will have a modernized map

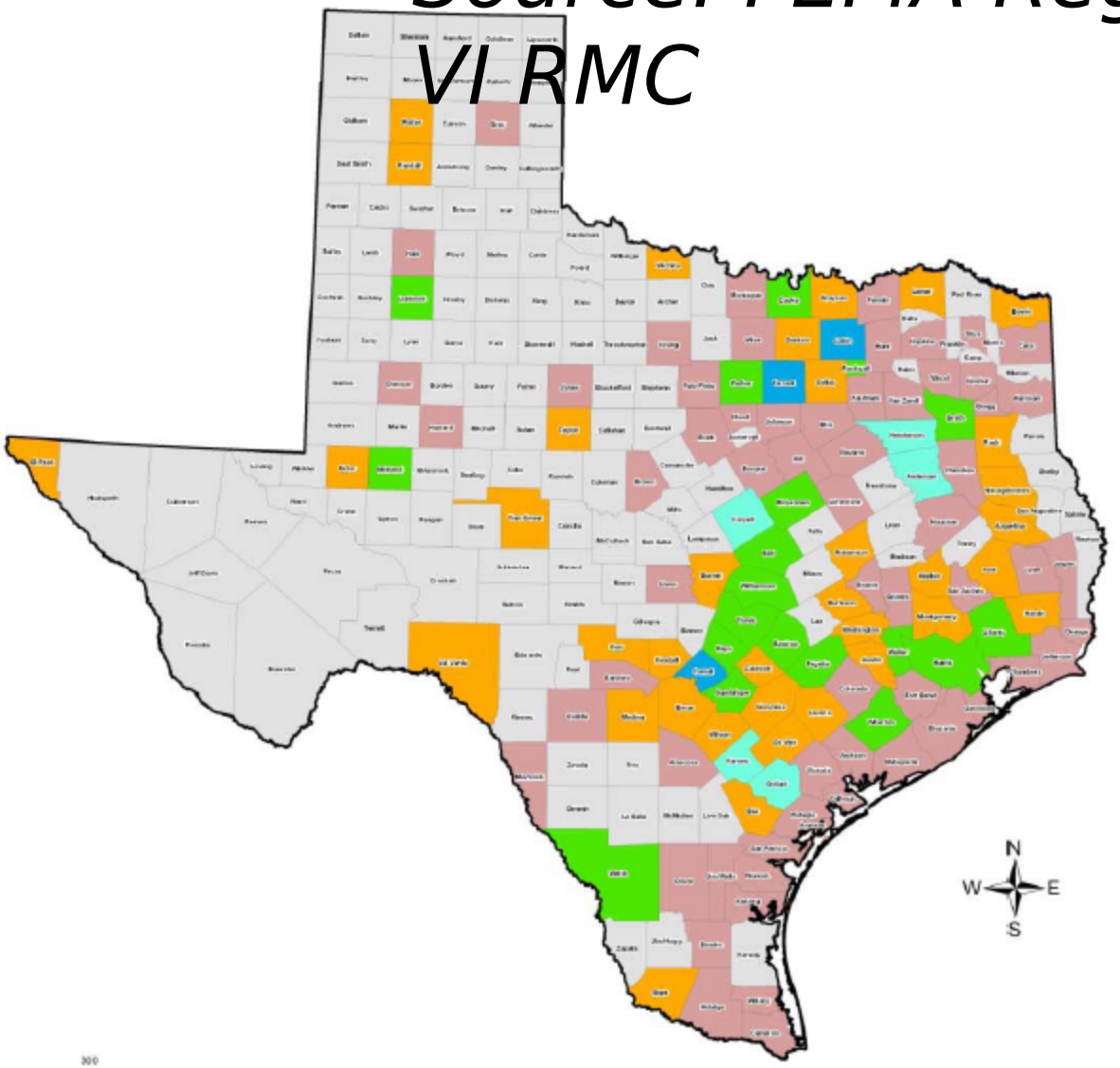
LEGEND

- Meets or Exceeds National Flood Hazard Data Quality Thresholds
- Approaches National Flood Hazard Data Quality Thresholds
- Digital Product Issued
- Modernized Map Not Yet Issued
- Study Not Planned

21% of population has maps meeting the floodplain boundary standard and engineering study standard

Map Modernization in Texas

Source: FEMA Region VI RMC

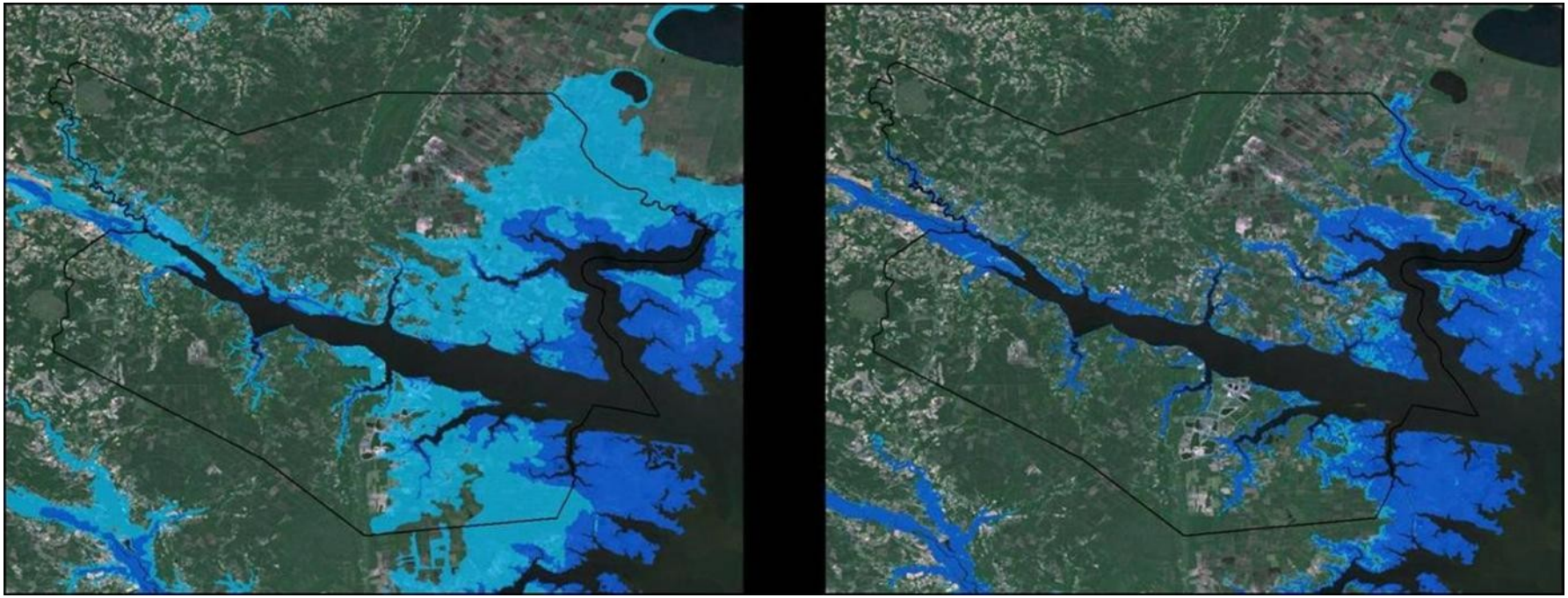


Map Modernization in Texas

	State Total	Current
Number of Counties Mapped	254	126
Percentage	100%	50%
Population in Mapped Counties	24,300,000	22,900,000
Percentage	100%	94%
Area of Counties Mapped (sq mi)	264,708	119,448
Percentage	100%	45%

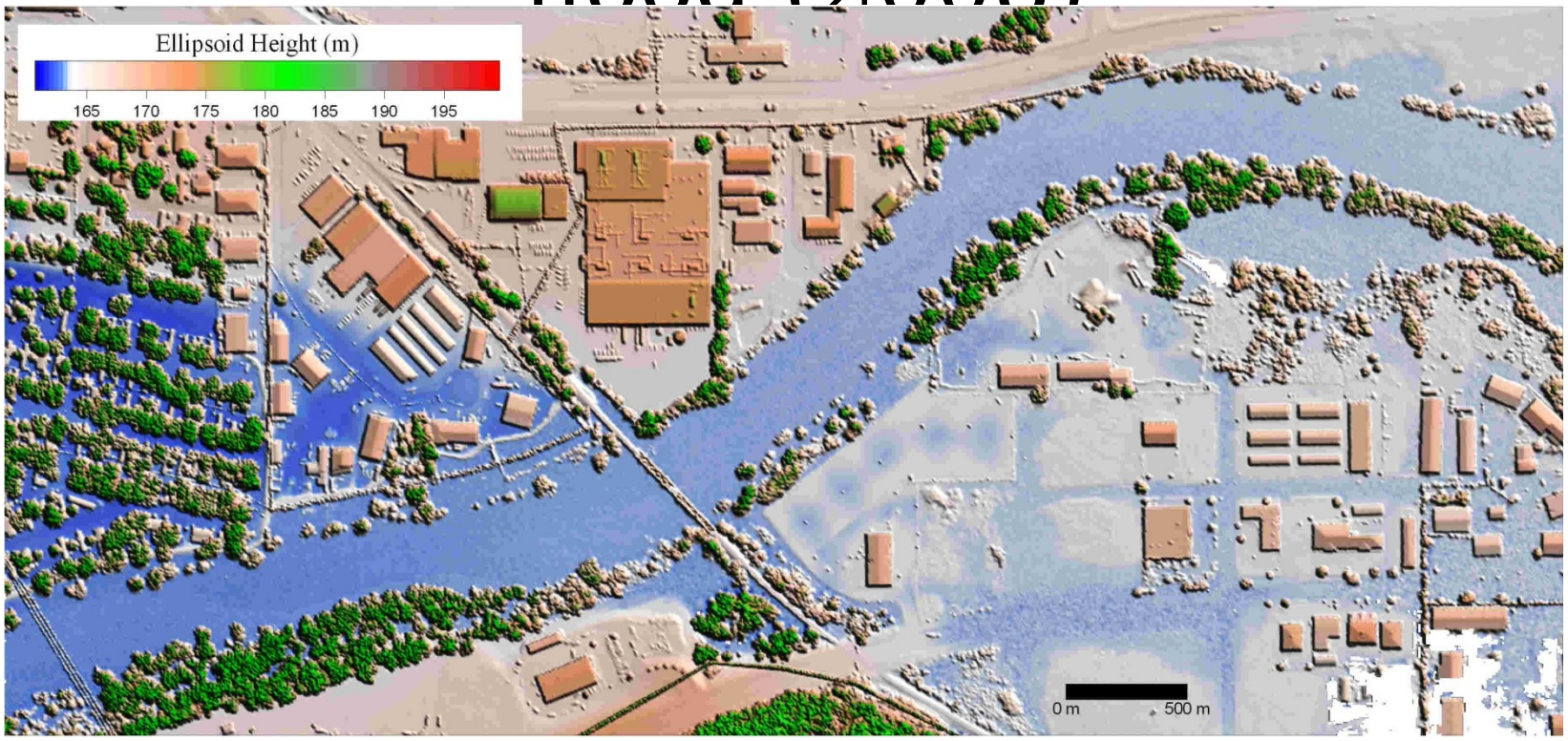
Terrain data accuracy matters

USGS NED (30m) NCFMP Lidar (3m)



Inundation for a 1ft storm surge or sea level rise in the Tar-Pamlico estuary (Source: USGS)

Lidar of inundated water surface elevation during Iowa flood (2008)



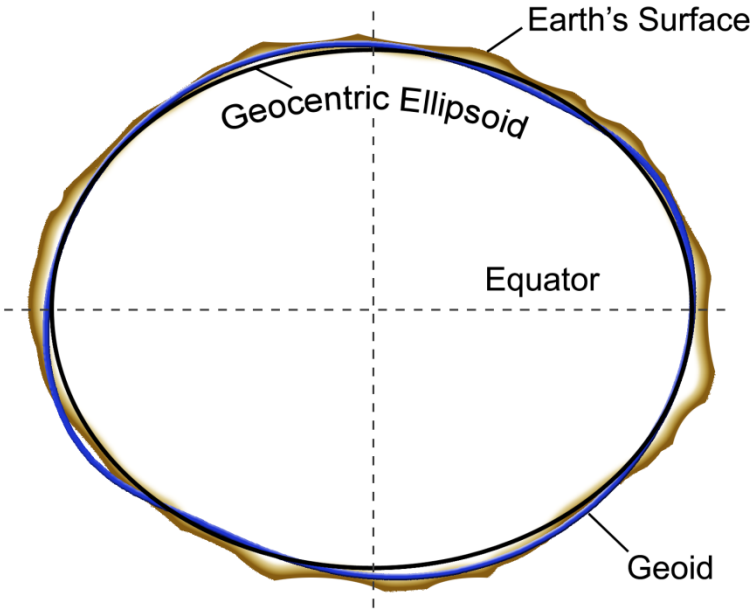
Source: University of Iowa and National Center for Airborne Laser Mapping

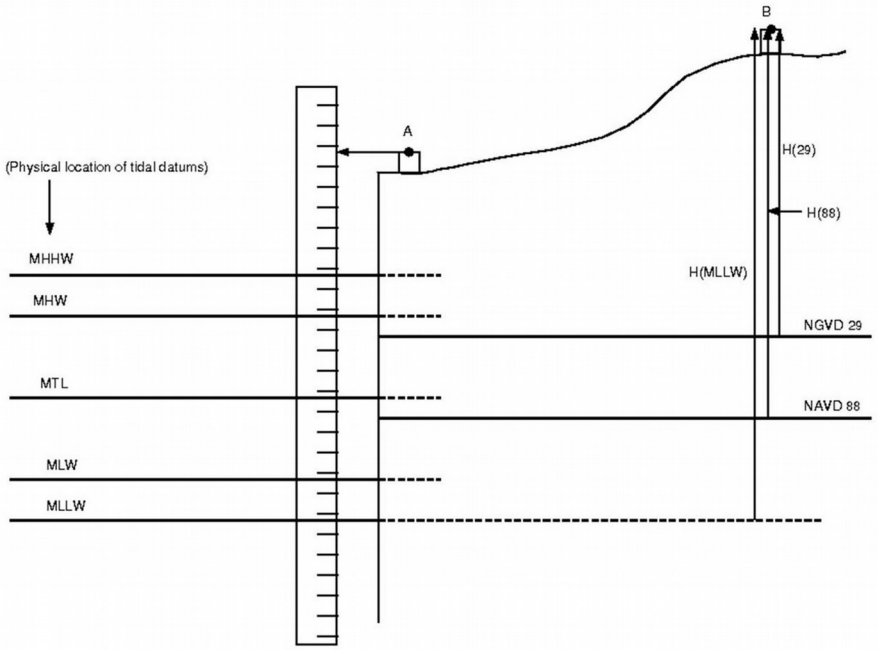
Three systems for measuring elevation

Orthometric heights (land surveys, geoid)

Ellipsoidal heights (lidar, GPS)

Tidal heights (Sea water level)

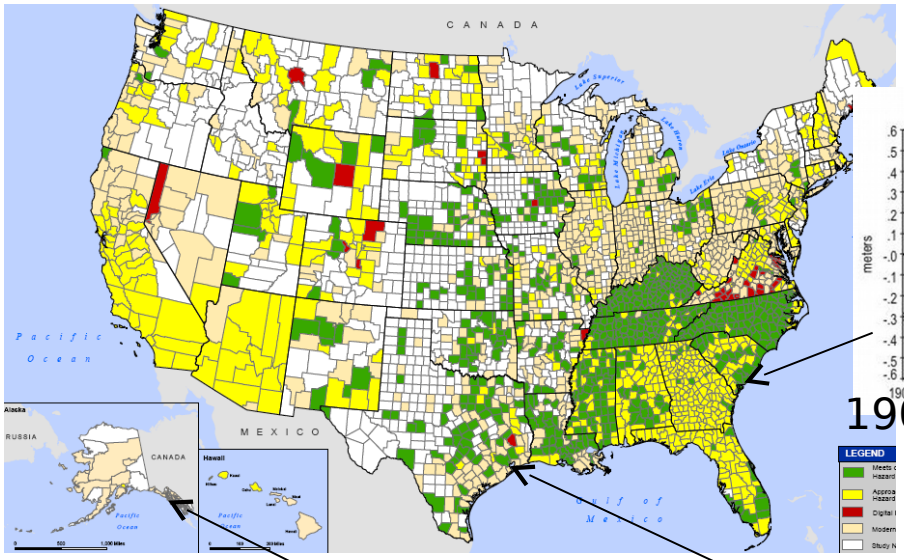




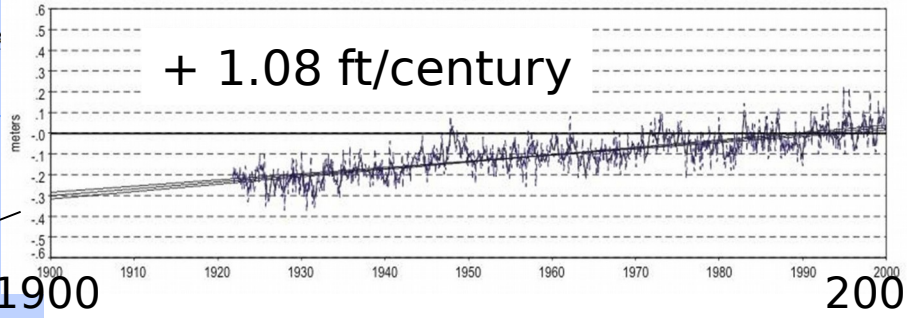
Improved reconciliation of these three systems is needed

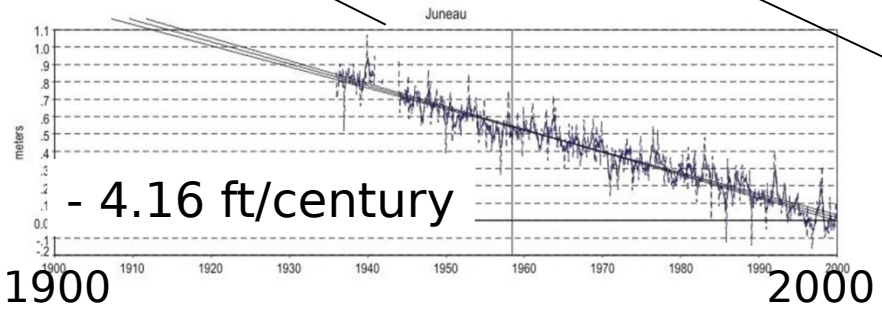
Trends in Tide Levels

(coastal flood risk is changing)



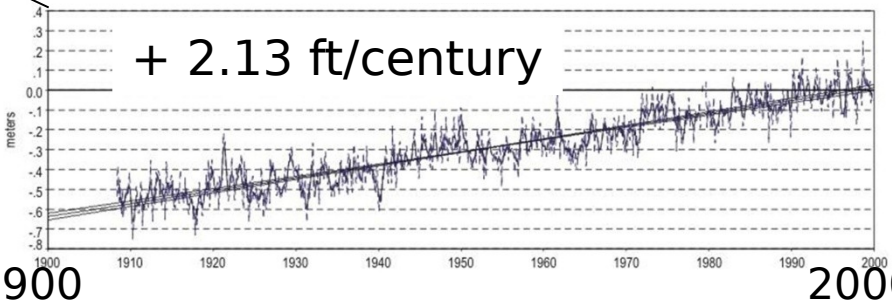
Charleston, SC



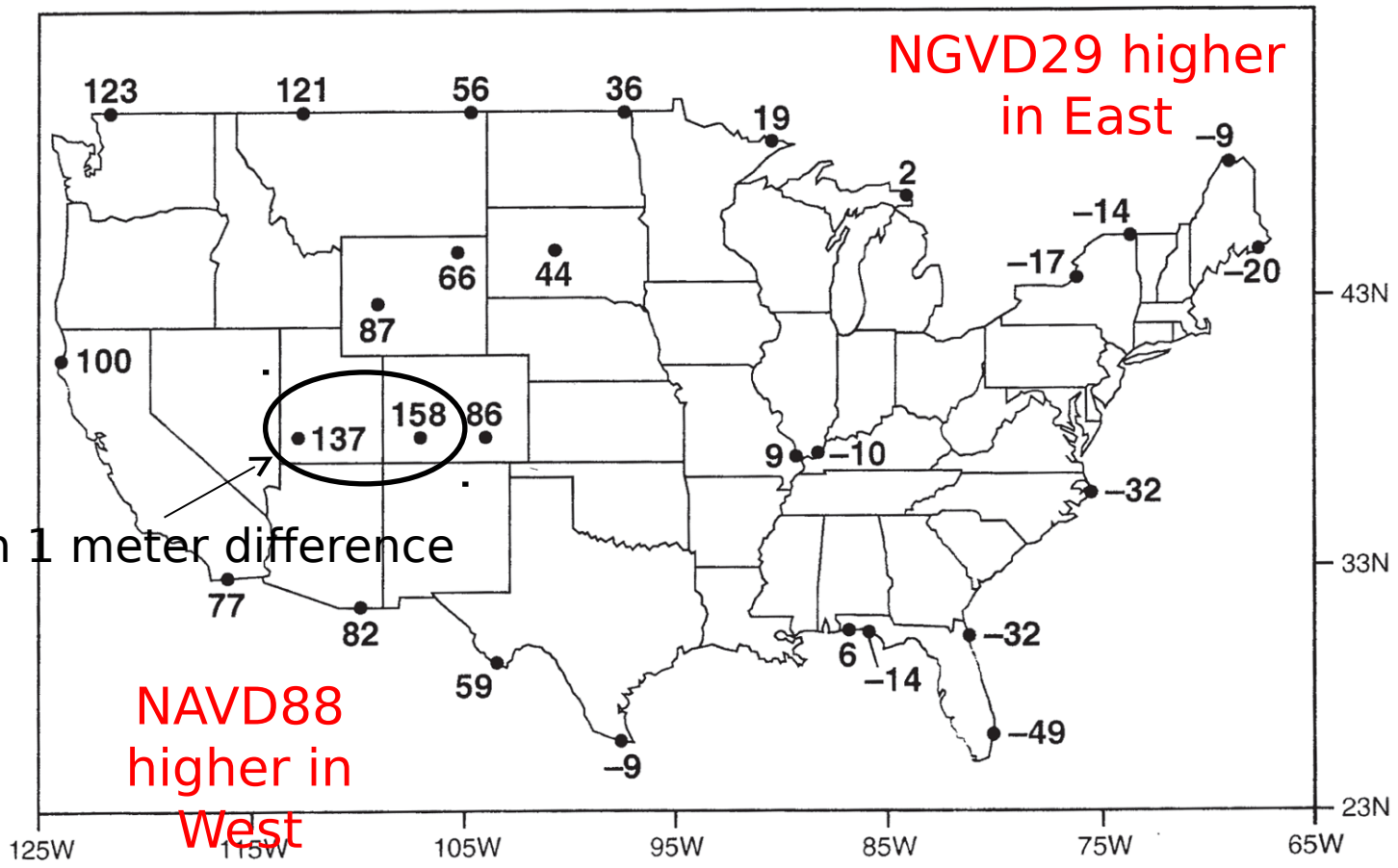


Juneau, AK

Galveston, TX



Importance of geodetic datums



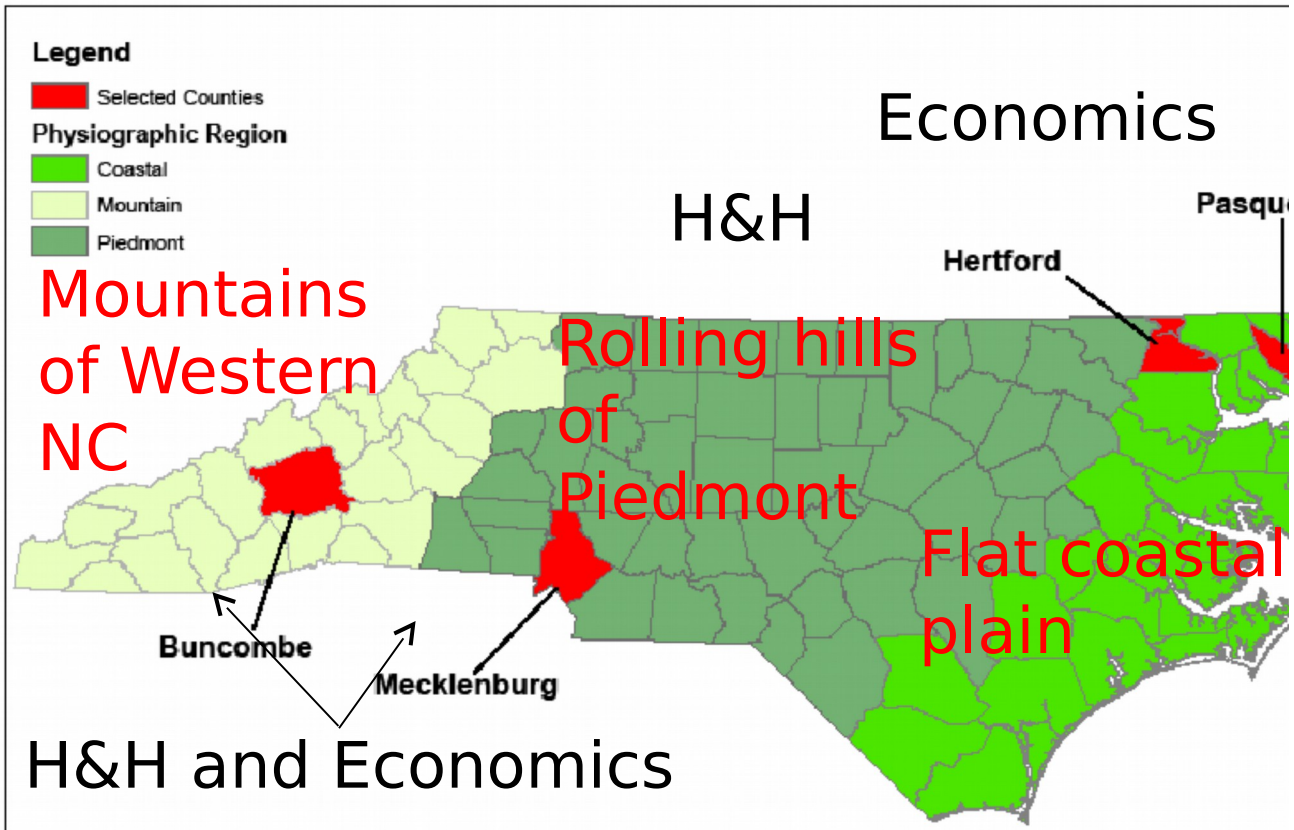
More than 1 meter difference

Orthometric datum height shifts are significant relative to BFE accuracy, so standardization on NAVD88 is justified

North Carolina Case Studies

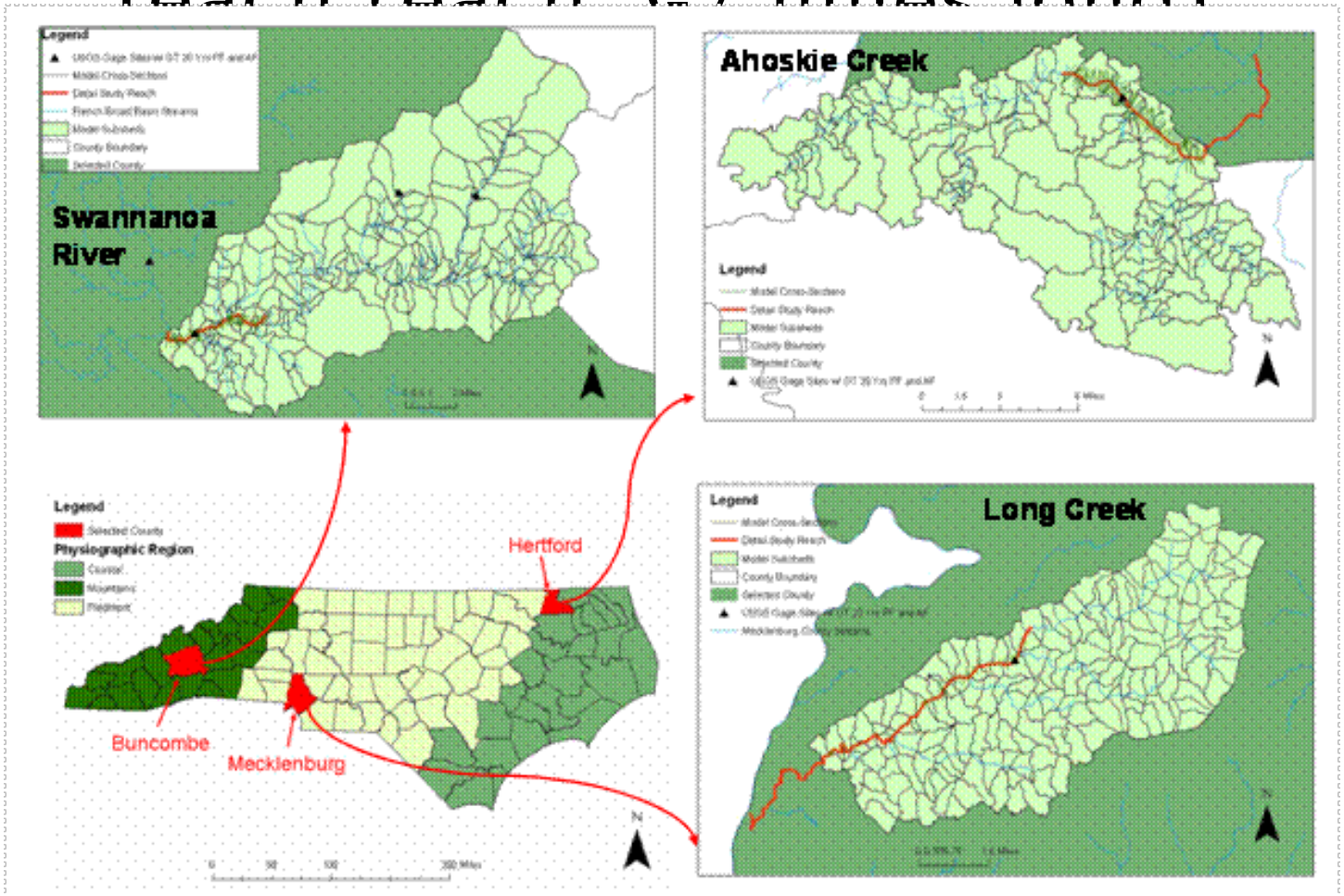
http://ww
m

Studies done for the NRC Committee by the North Carolina Floodplain Mapping Program (NCFMP)



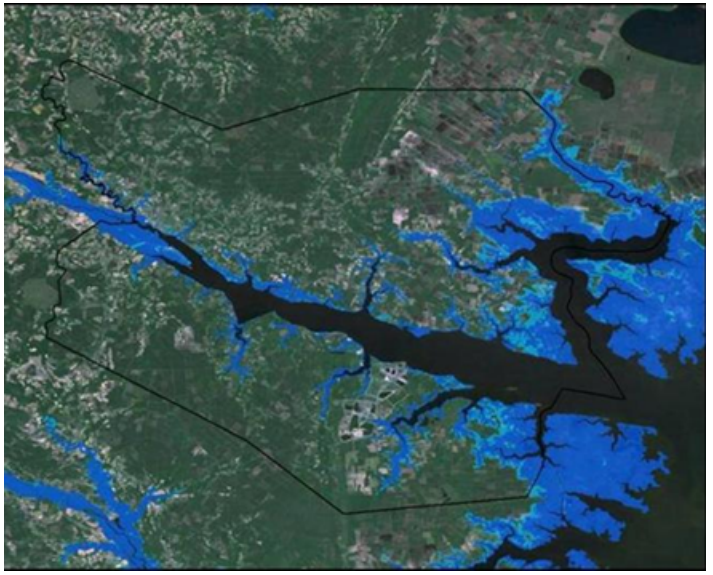
(H&H = Hydrology and Hydraulics)

One River Reach studied in detail in each region
(each reach 5-7 miles long)



Terrain Data for Case Studies

USGS DEMs (30m)



NCFPM Lidar (3m)

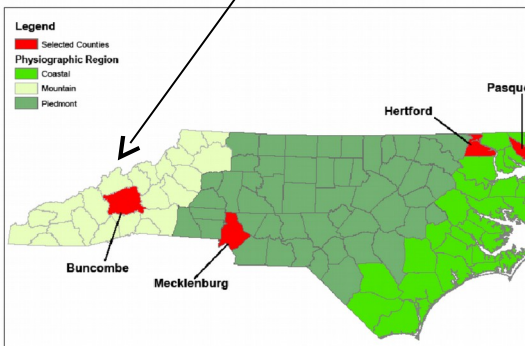
Swannanoa River, Buncombe County, NC

NED - Lidar

Elevation Difference

- < -40 feet
- -40 to -15 feet
- -15 to -2 feet
- -2 to 2 feet
- 2 to 15 feet
- 15 to 40 feet
- > 40 feet

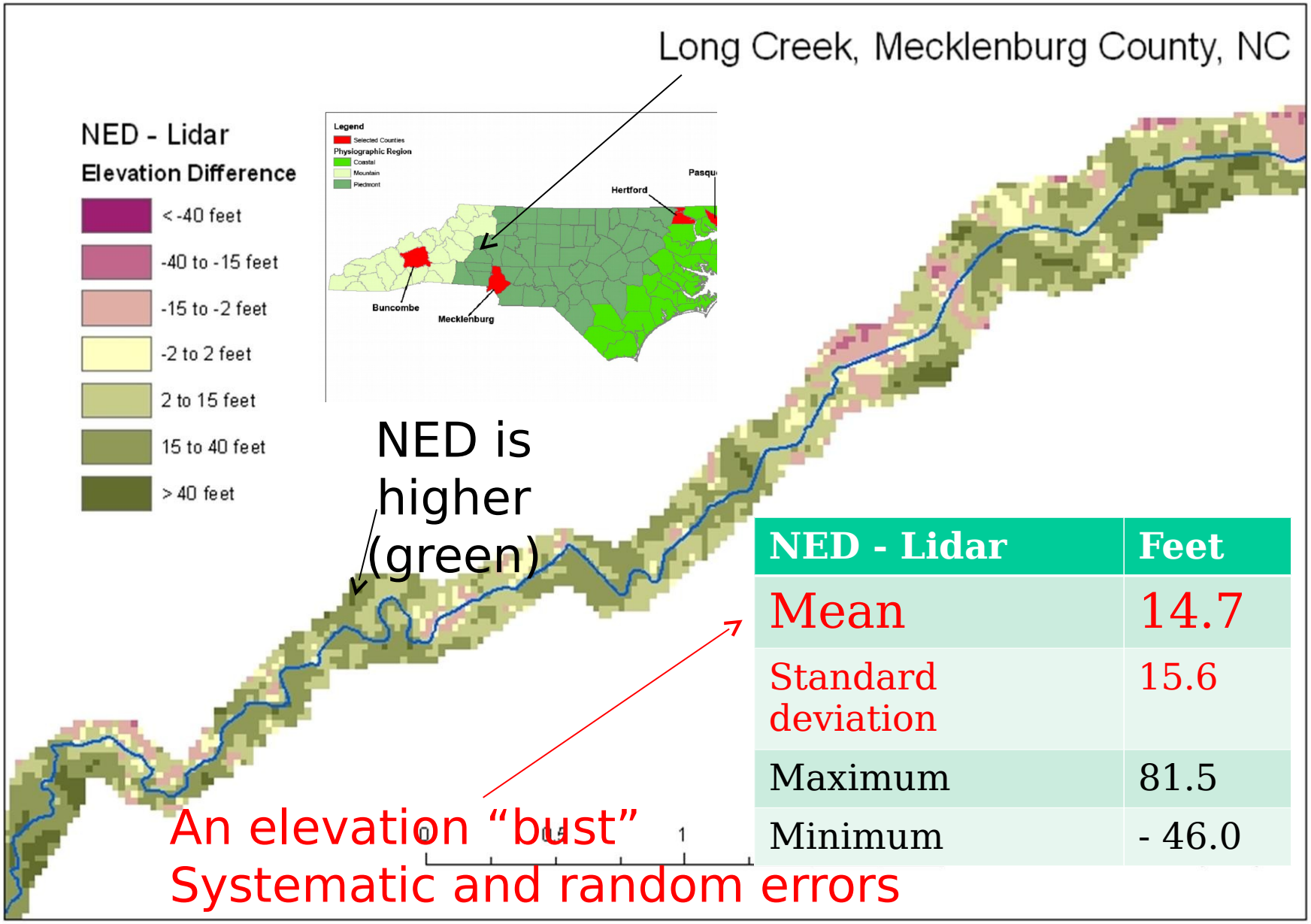
NED - Lidar	Feet
Mean	-2.0
Standard deviation	17.5
Maximum	89.7
Minimum	-139.3



NED is higher (green)

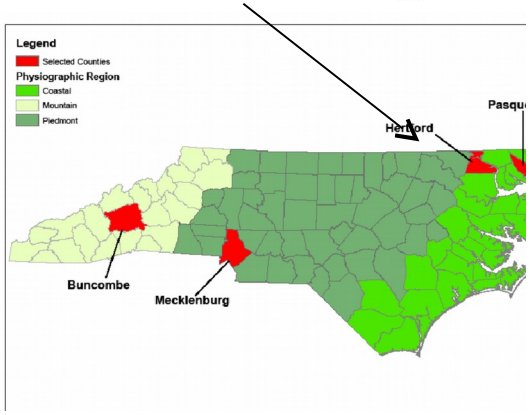
Lidar is higher (purple)

0 0.5 1 2 Miles



NED - Lidar	Feet
Mean	14.7
Standard deviation	15.6
Maximum	81.5
Minimum	- 46.0

Ahoskie Creek, Hertford County, NC



Text

NED - Lidar

Elevation Difference

- < -40 feet
- -40 to -15 feet
- -15 to -2 feet
- -2 to 2 feet
- 2 to 15 feet
- 15 to 40 feet
- > 40 feet

NED - Lidar	Feet
Mean	0.5
Standard deviation	3.9
Maximum	34.8
Minimum	-25.3

Terrain Data

- Our study demonstrates that there are large differences between LIDAR and NED
  - Random differences everywhere
  - Systematic differences in some places

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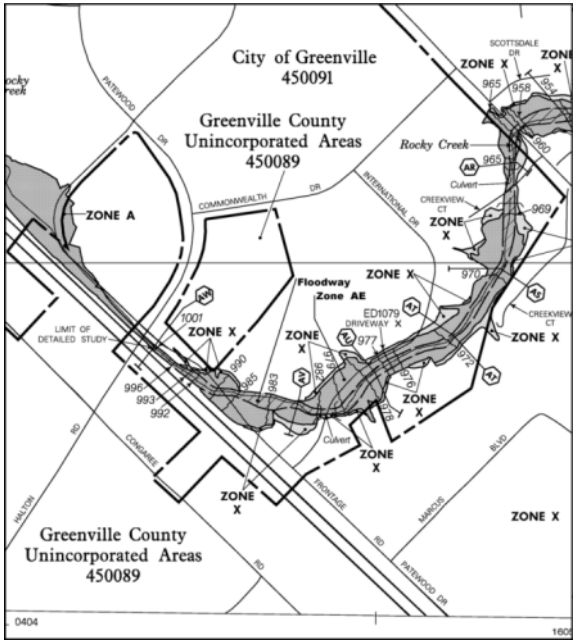
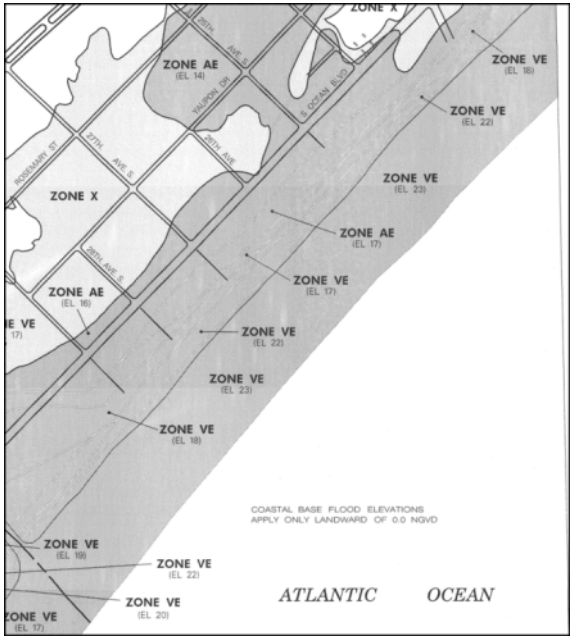
Flood Maps

Riverine



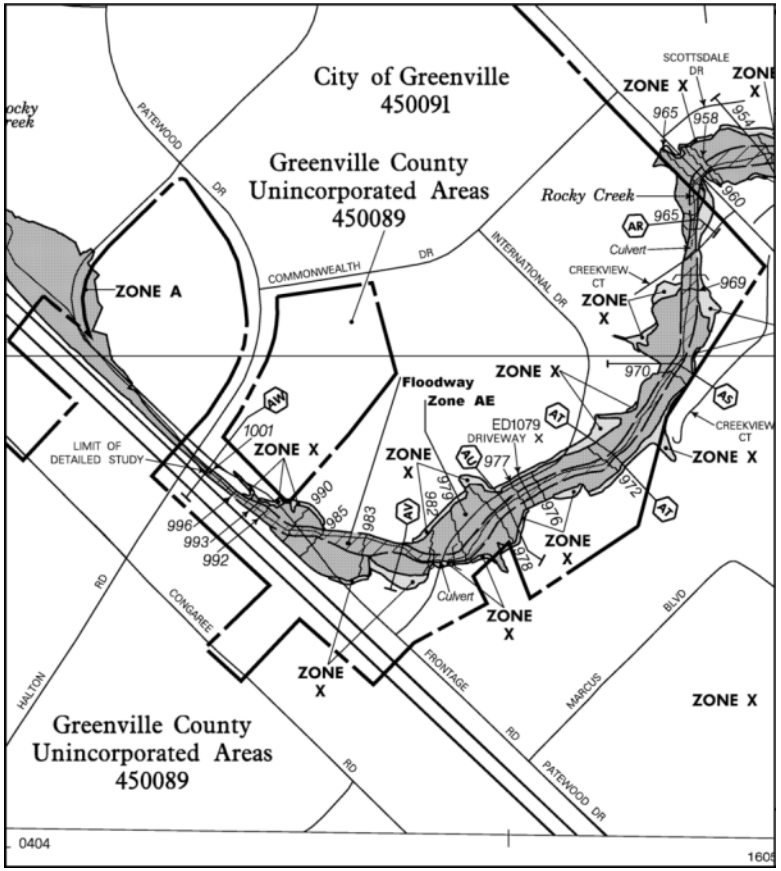
Coastal



Two very different flood modeling and mapping problems

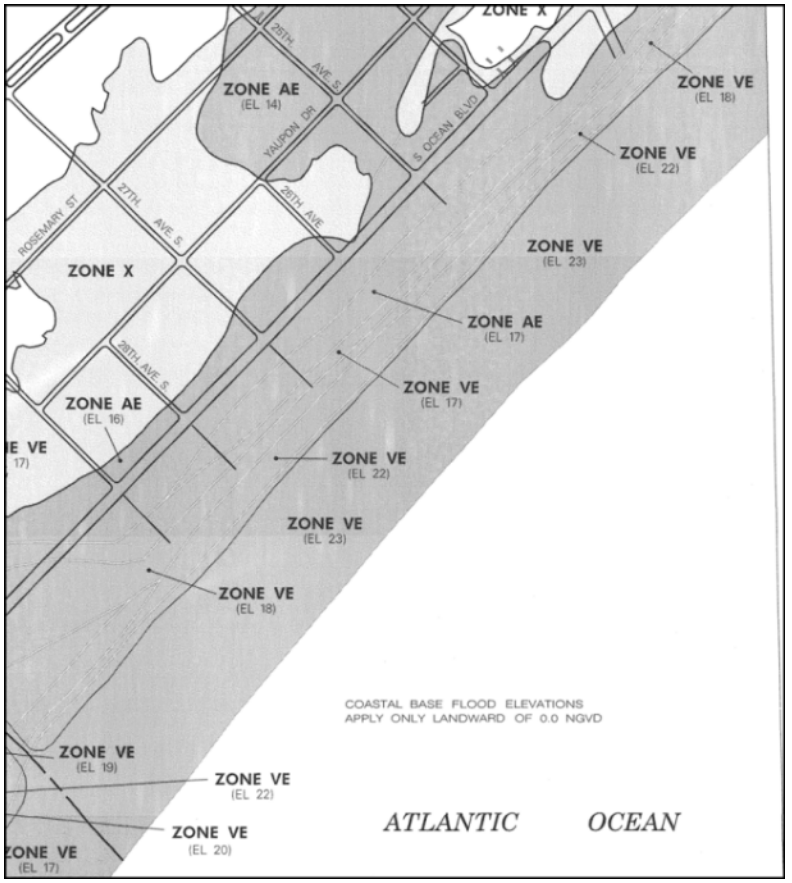
Riverine Flood Mapping

- Modeling and mapping technology is well established
- Supported by a large observation database at stream gages
- Floods flow along the line of the stream gages



Coastal Flood Mapping

- Modeling and mapping technology and guidance are evolving
- Storm surges inland transverse to the line of tide gages
- Large dependence on models, less on historical flood data

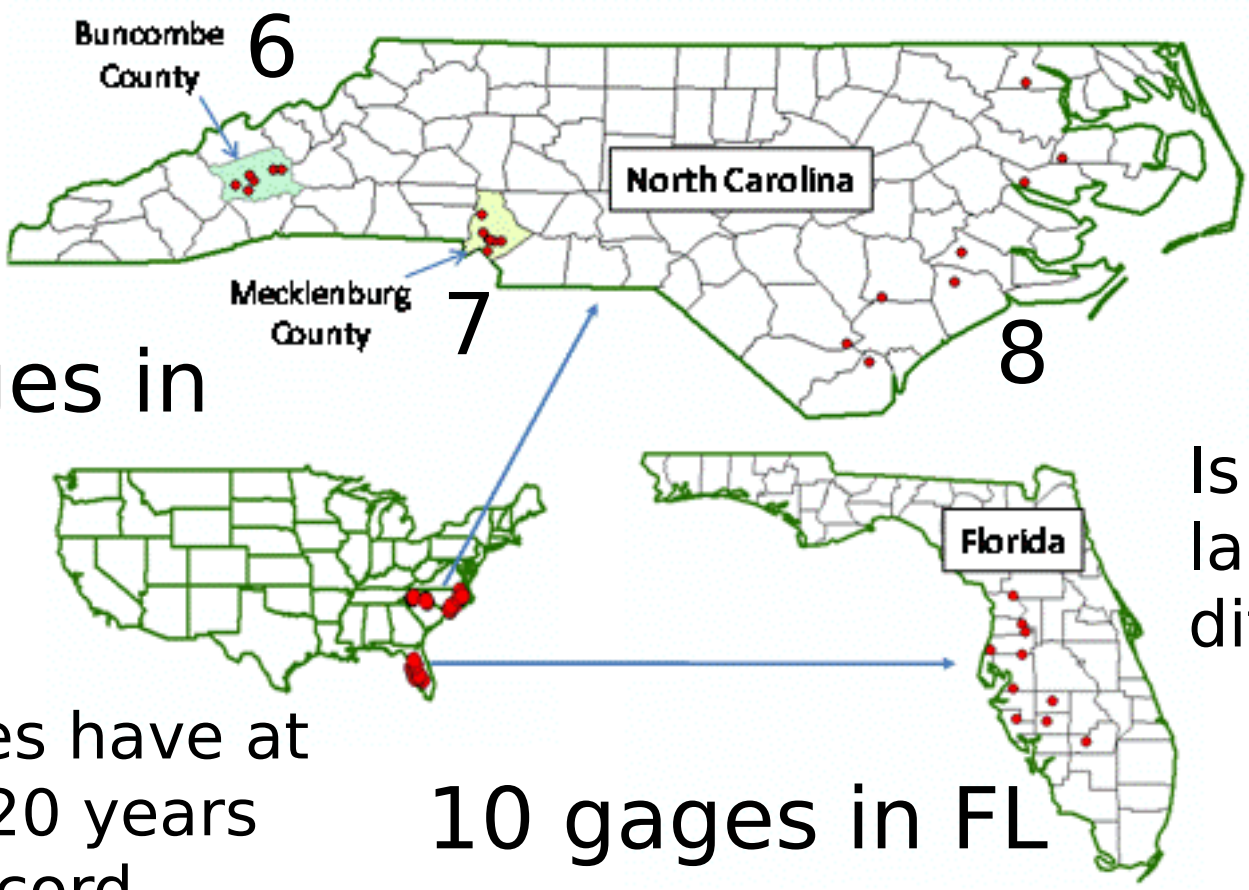


Defining Uncertainty in BFE

Long term records of extreme stages recorded at USGS gages

At each gage the peak stage is recorded for each year along with the peak flow – do a frequency analysis of these.

Frequency Analysis of Stage Heights at 31 gages



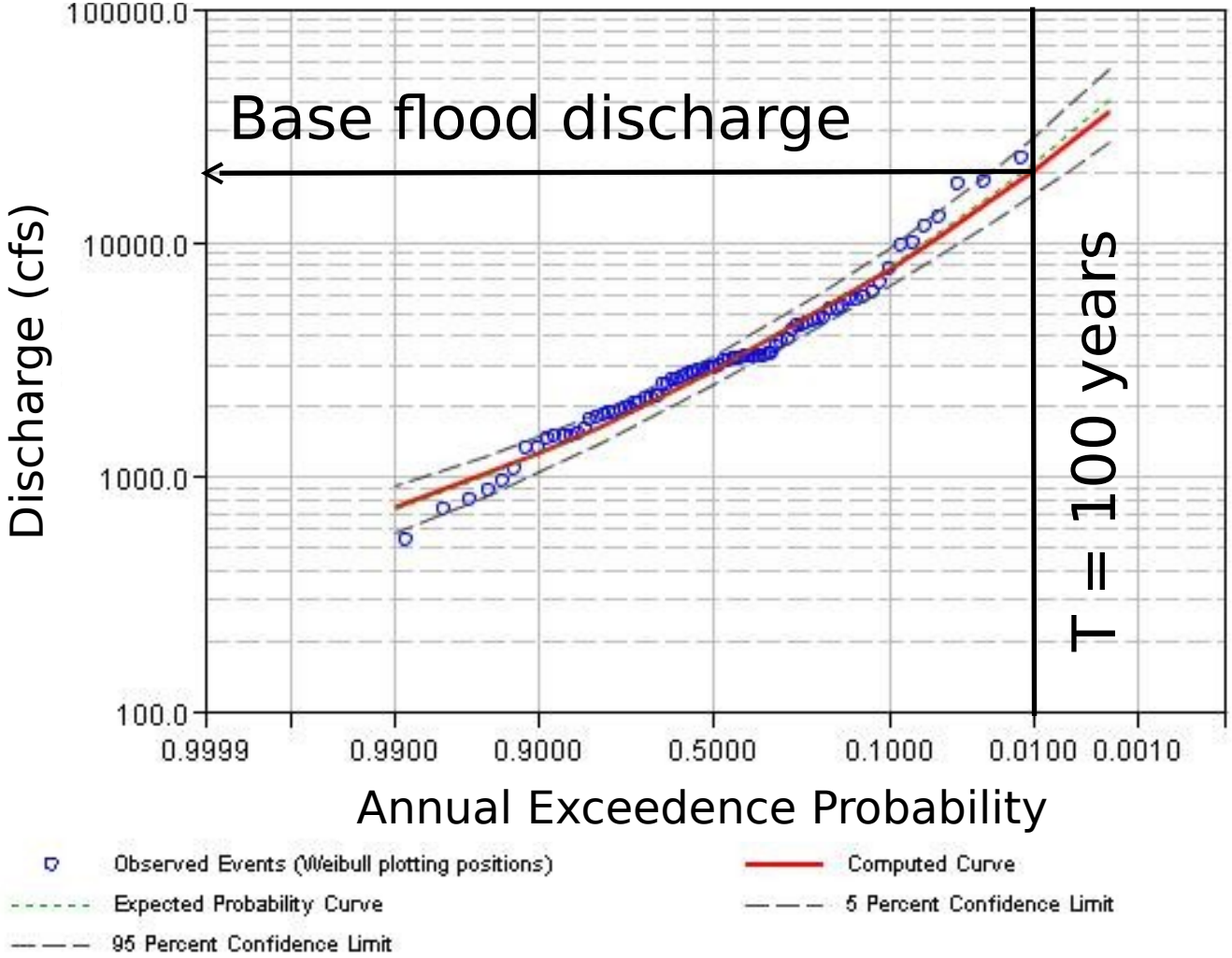
21 gages in NC

Is pitted FL landscape different?

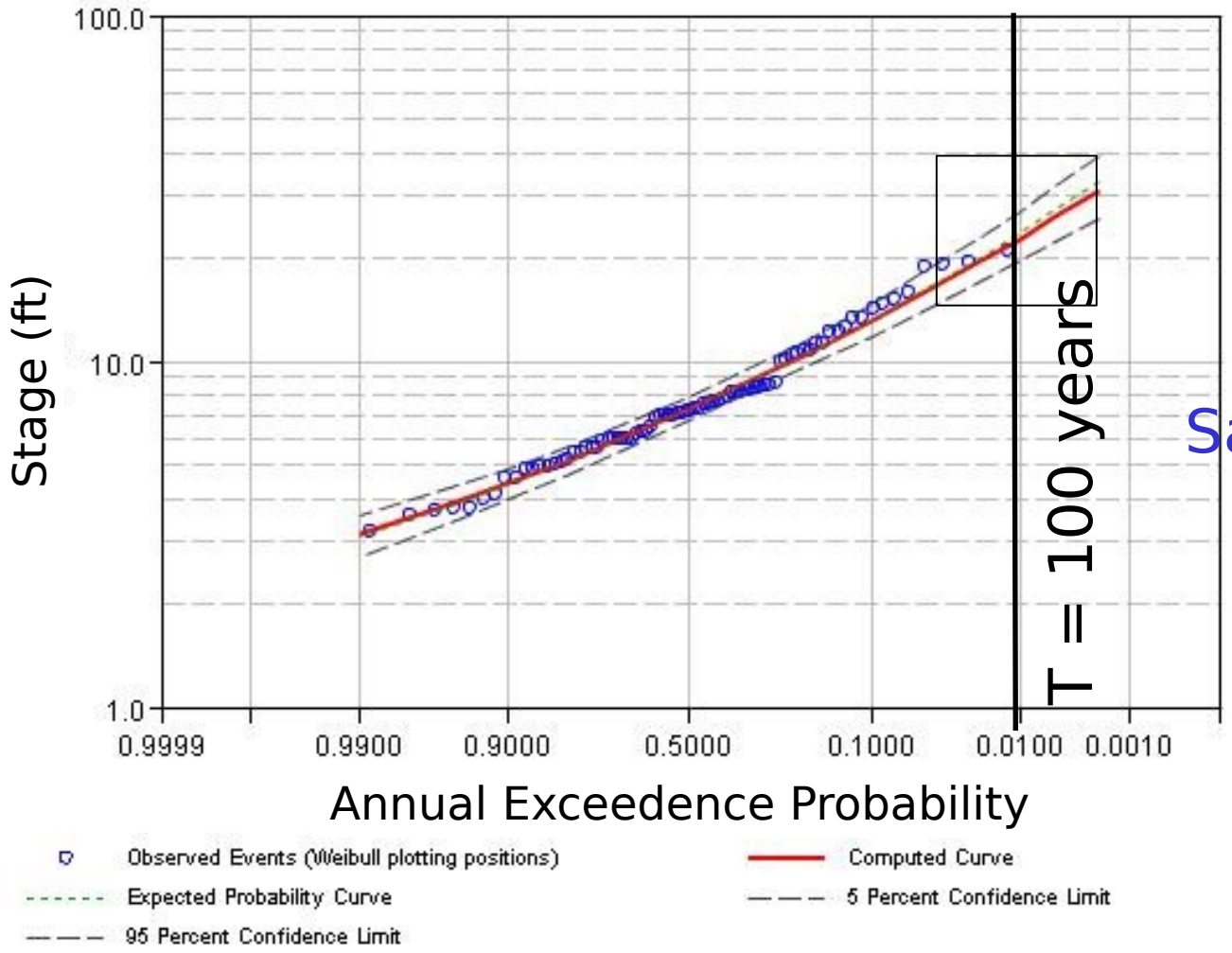
All gages have at least 20 years record (average is 54 years)

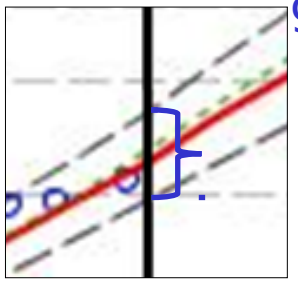
10 gages in FL

Swannanoa River at Biltmore, NC (78 years of record)



Produced using the Corps HEC-SSP Program
(Bulletin 17-B standard procedure)



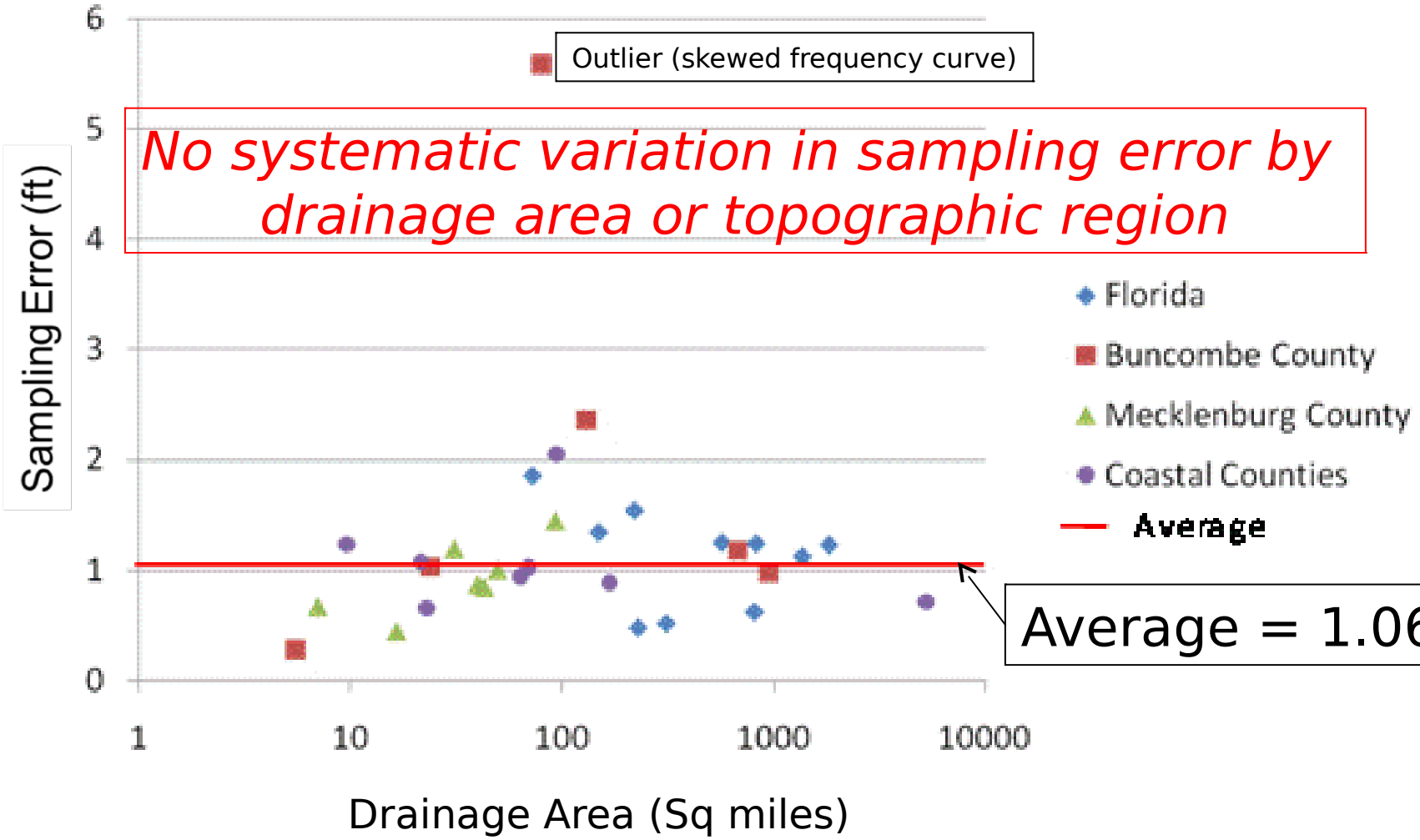


Sampling error =

$$\frac{95\%CL - 5\%CL}{3.29}$$

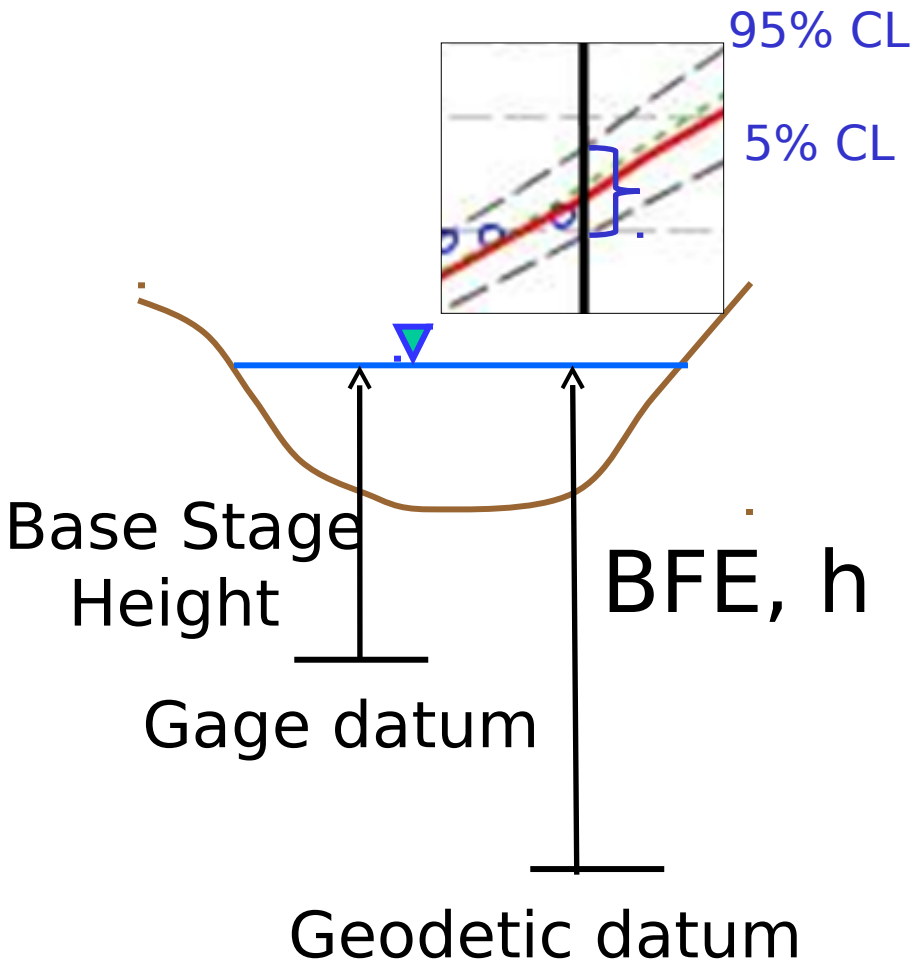
Uncertainty in BFE = Uncertainty in 100-year stage height

Sampling Error of 100-year Stage Heights



Uncertainty in BFE

- BFE and Base Stage Height differ by a constant amount (gage datum – geodetic datum)
- This doesn't affect uncertainty of statistical variation of sample data around the 100-year estimate
- Average value of sample error at 30 of 31 gage sites is 1.06 ft
- *A **Lower Bound** on the uncertainty of the BFE is a standard error of estimate of approximately one foot*

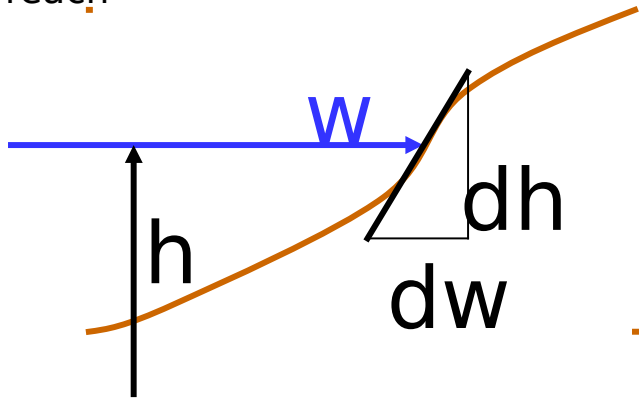


Uncertainty in Floodplain Boundary Location

dw/dh = Run/Rise

County	Lateral slope (%)	Run/rise (ft)
Ahoskie Creek	2.4	42
Long Creek	9.8	10
Swannanoa River	12.9	8

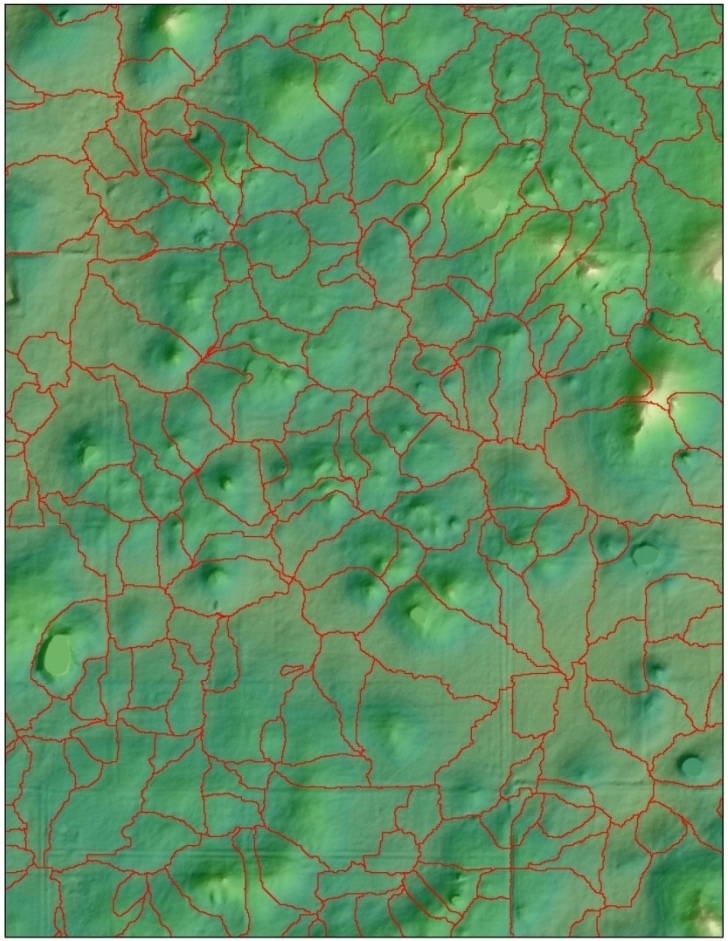
Lateral channel slope is calculated on HEC-RAS cross-sections at the point of intersection of water surface with land surface (left and right banks) and averaged for all cross-sections in the reach



*A **Lower Bound** on the uncertainty of the floodplain boundary location ranges from approximately 8ft in the mountains to approximately 40 ft in the coastal plain*

Interconnected Ponds (e.g. Florida)

- Gage study showed that BFE uncertainty in Florida rivers is similar to NC
- Many complex hydrologic issues inherent in how water reaches river from a ponded landscape
- *Needs a separate study*

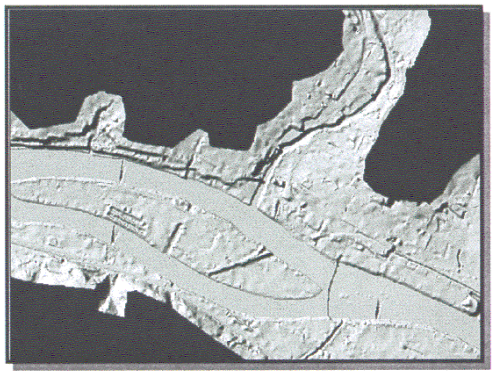


Data from SWFWMD

DFIRM Components

Imagery

+



Elevation

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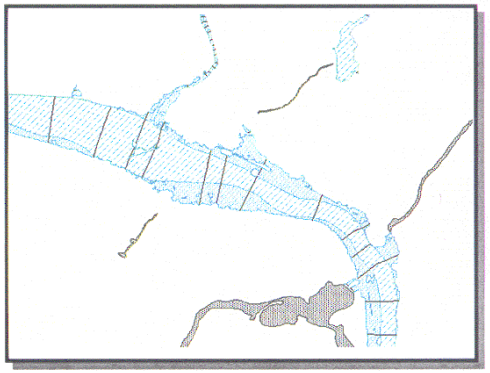
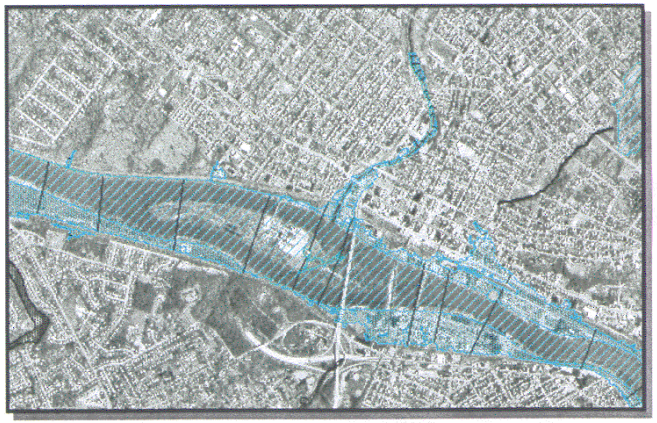


Flood Data

Alignment of planimetrics and elevation data really matters

=

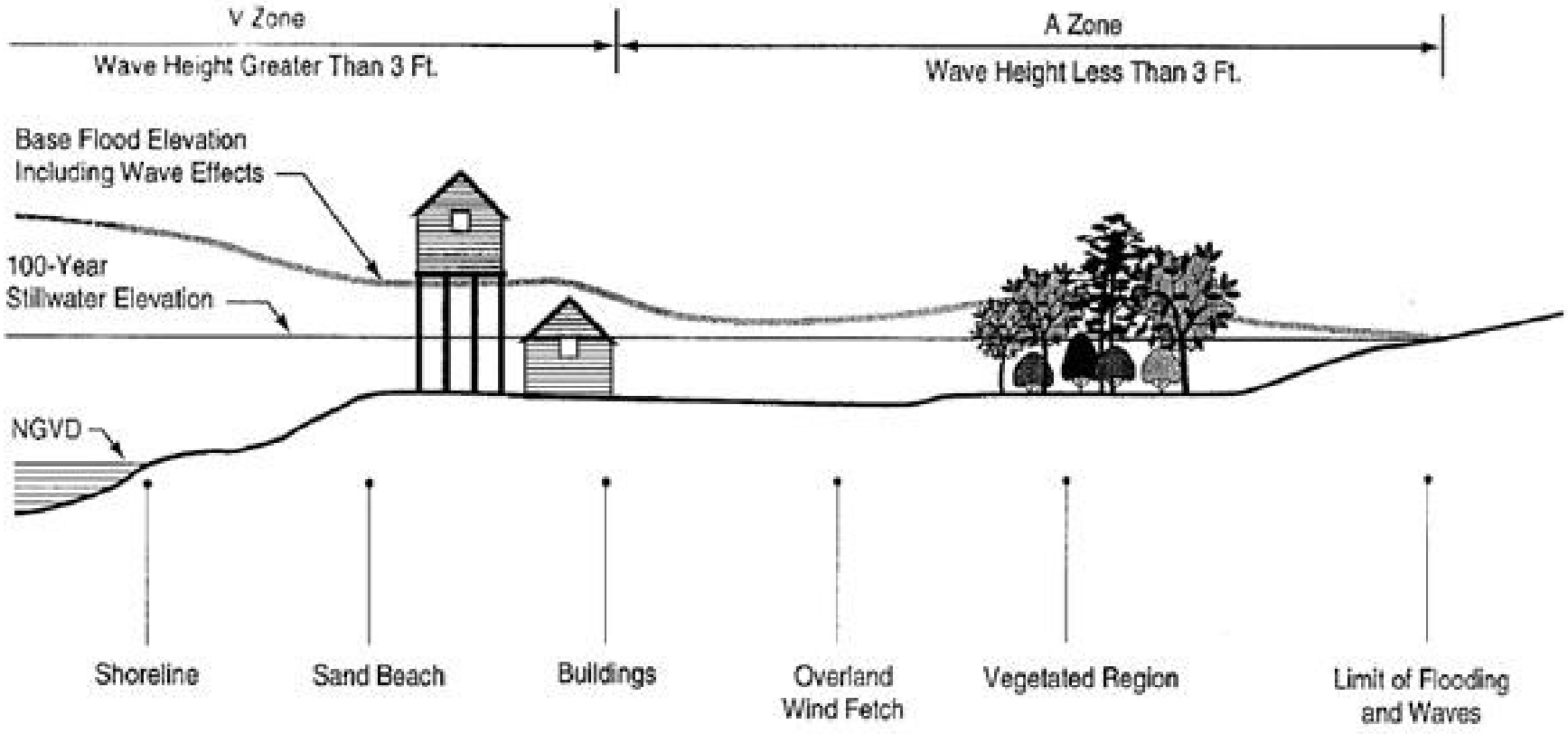


DFIRM

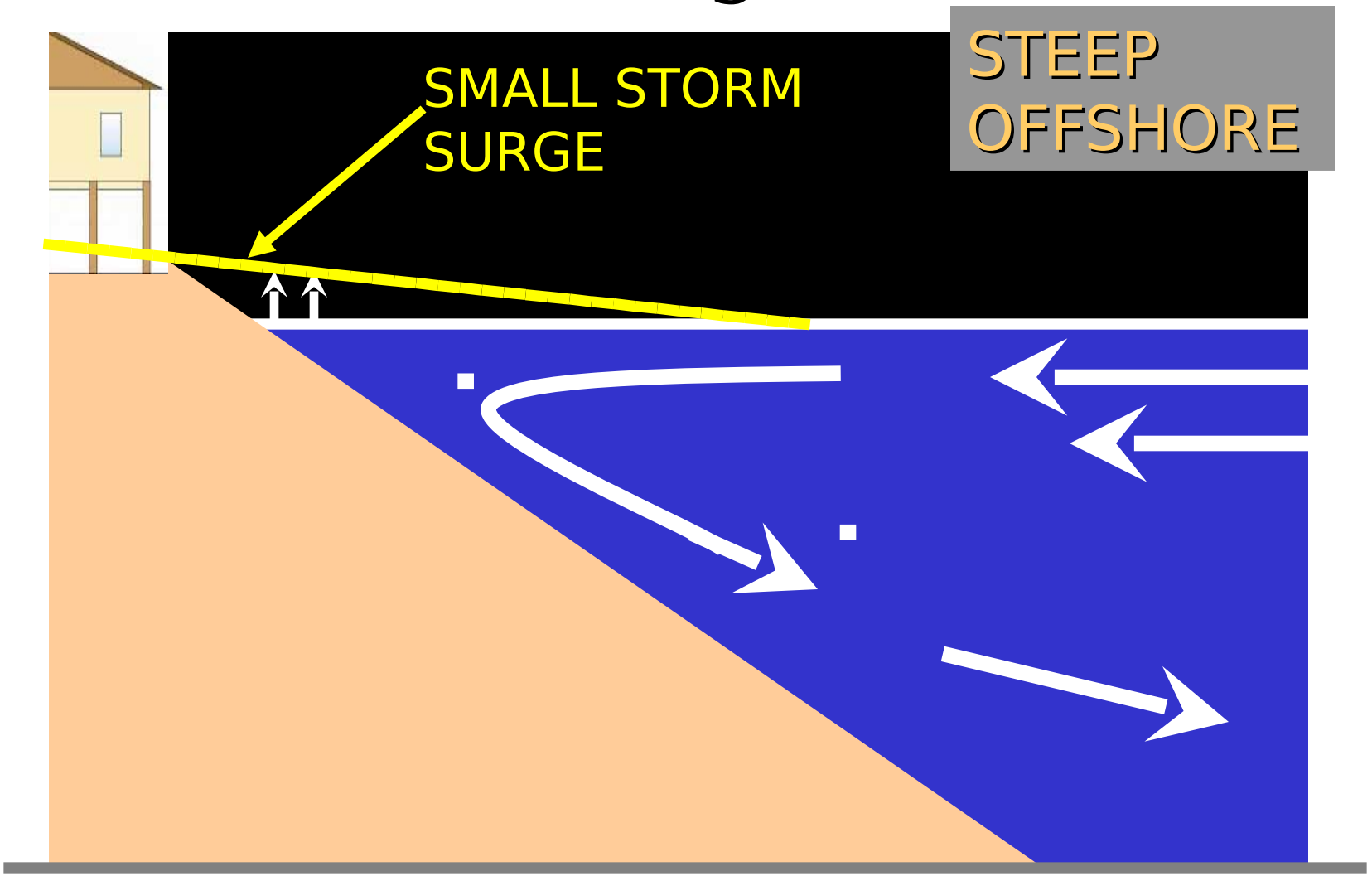
Overarching Finding

1. Topographic data is the most important factor in determining water surface elevations, base flood elevation, and the extent of flooding, and thus the accuracy of flood maps in riverine areas

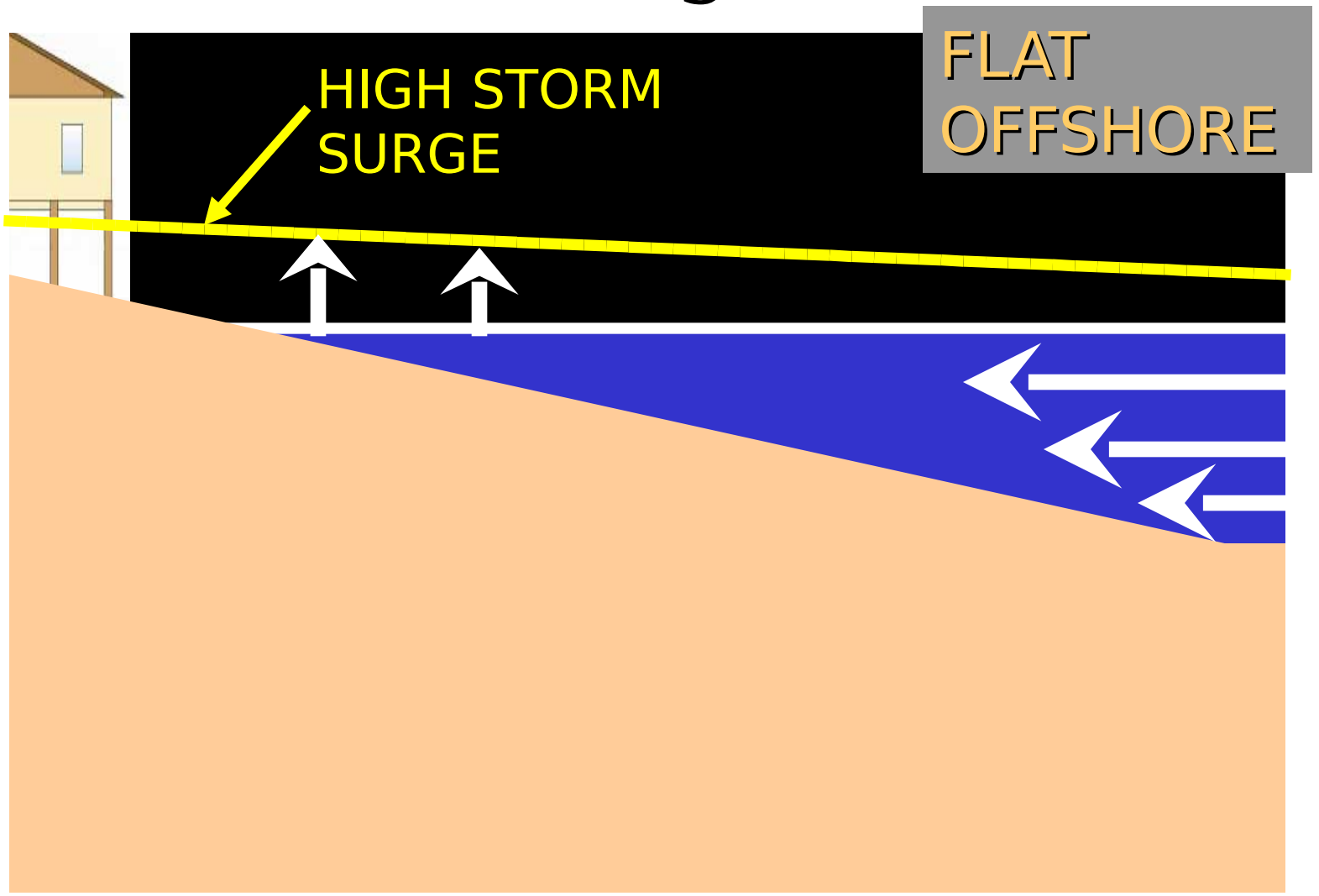
Coastal Flood Mapping



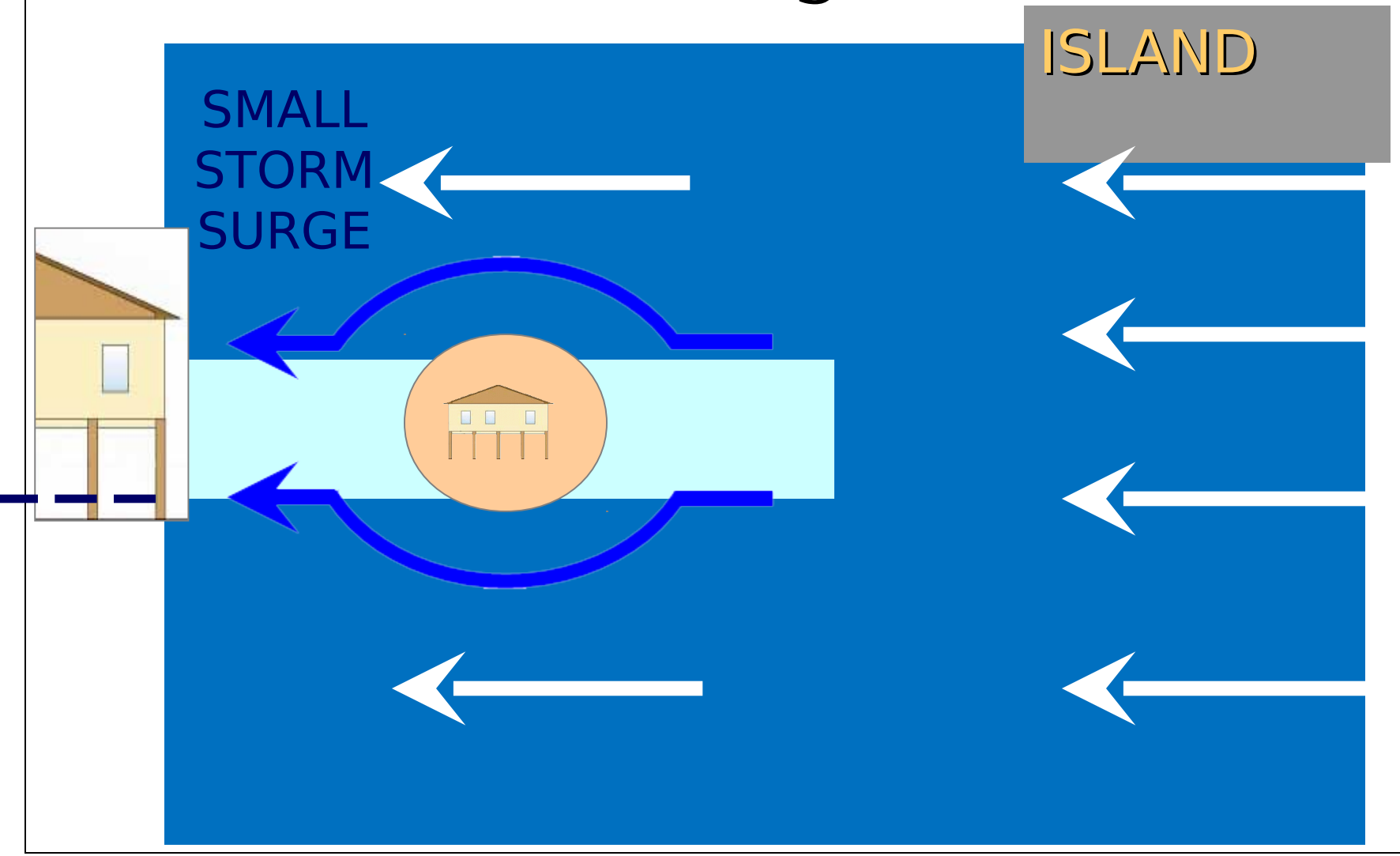
Storm Surge



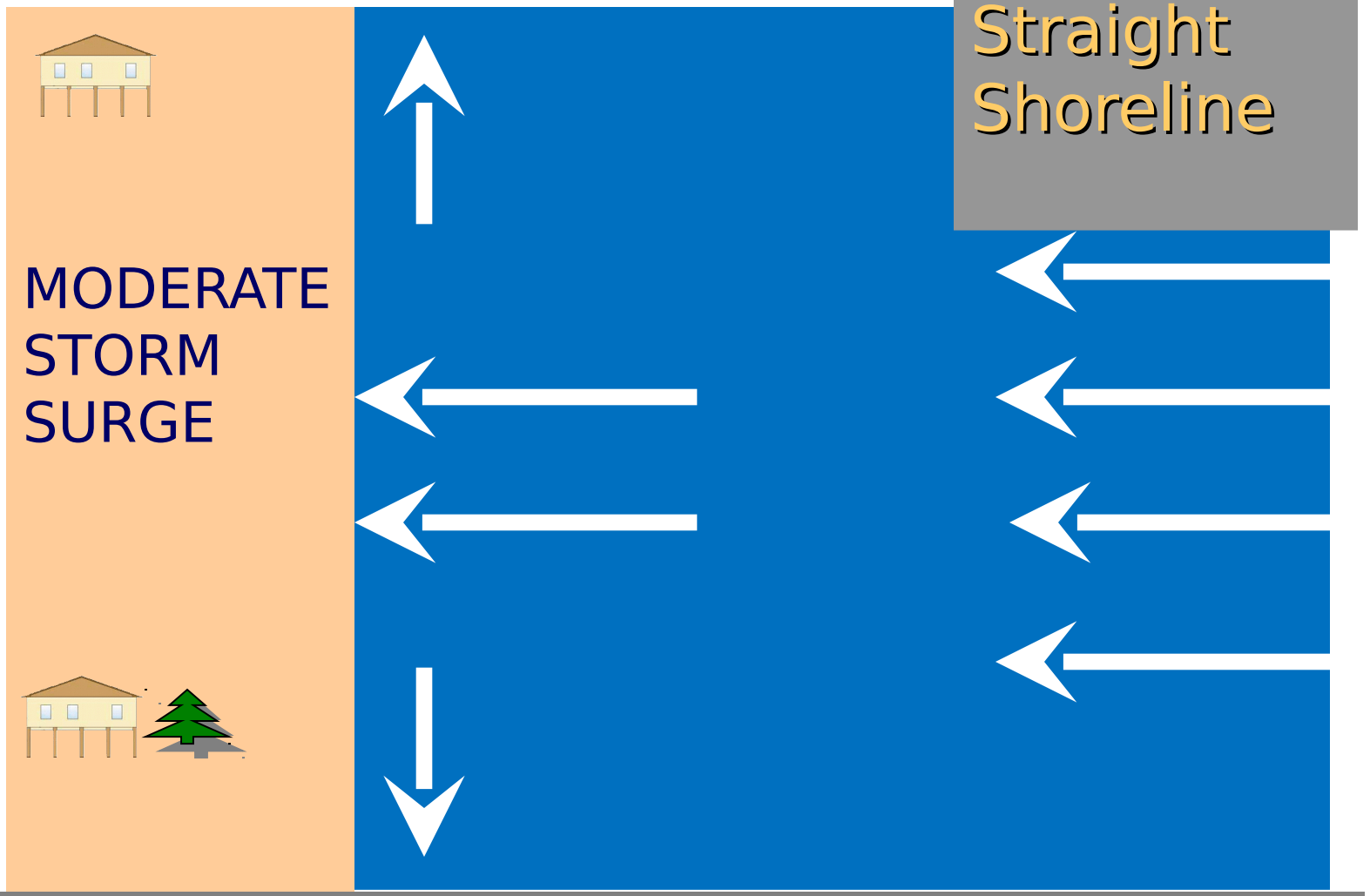
Storm Surge



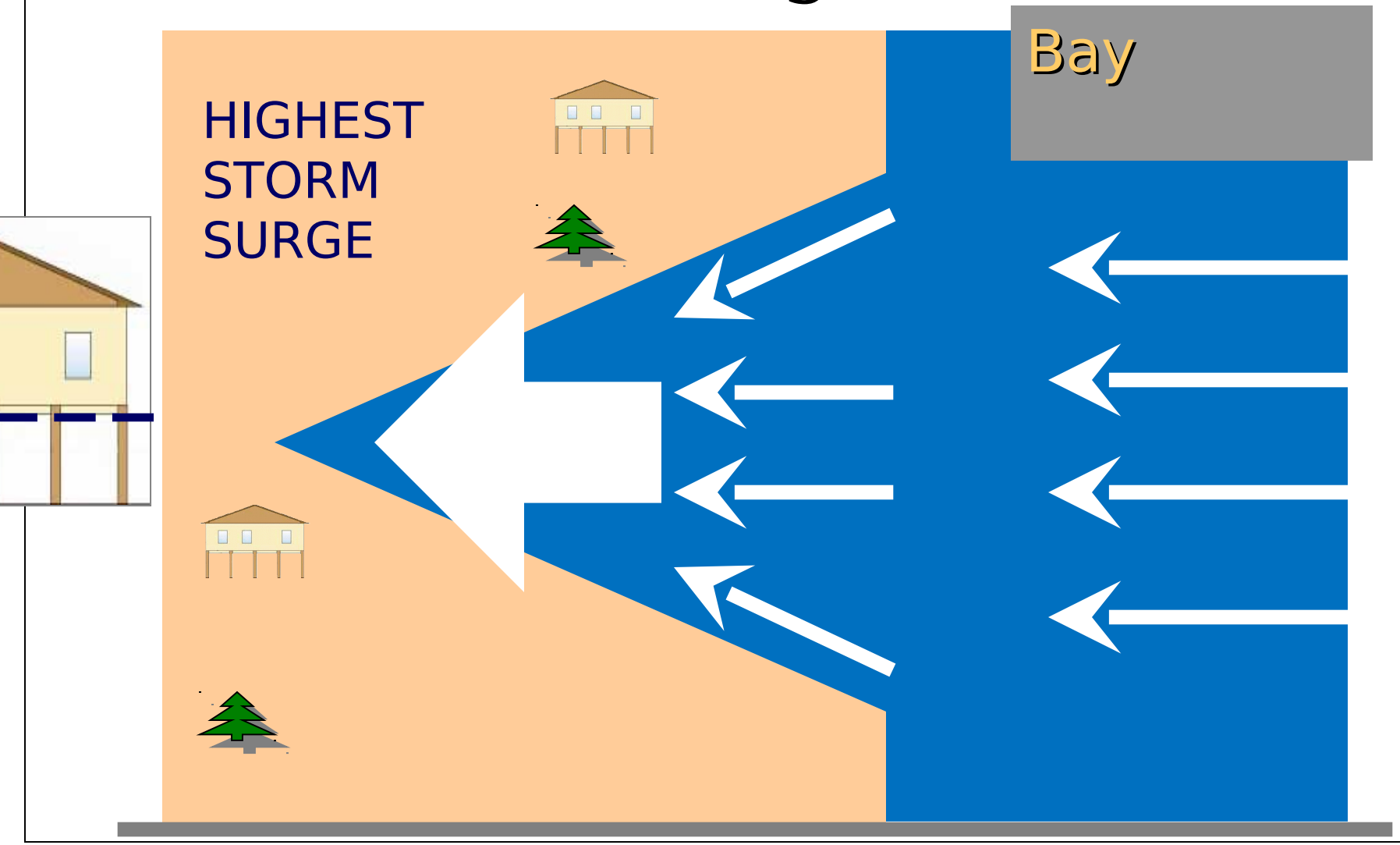
Storm Surge

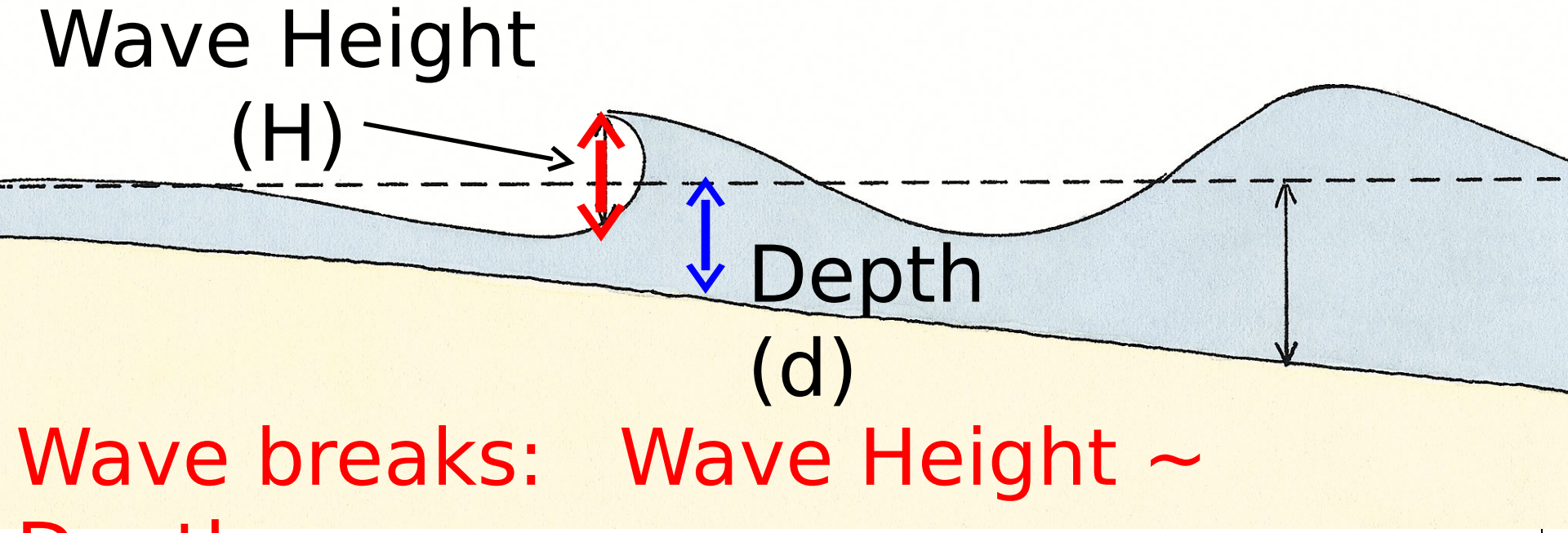


Storm Surge



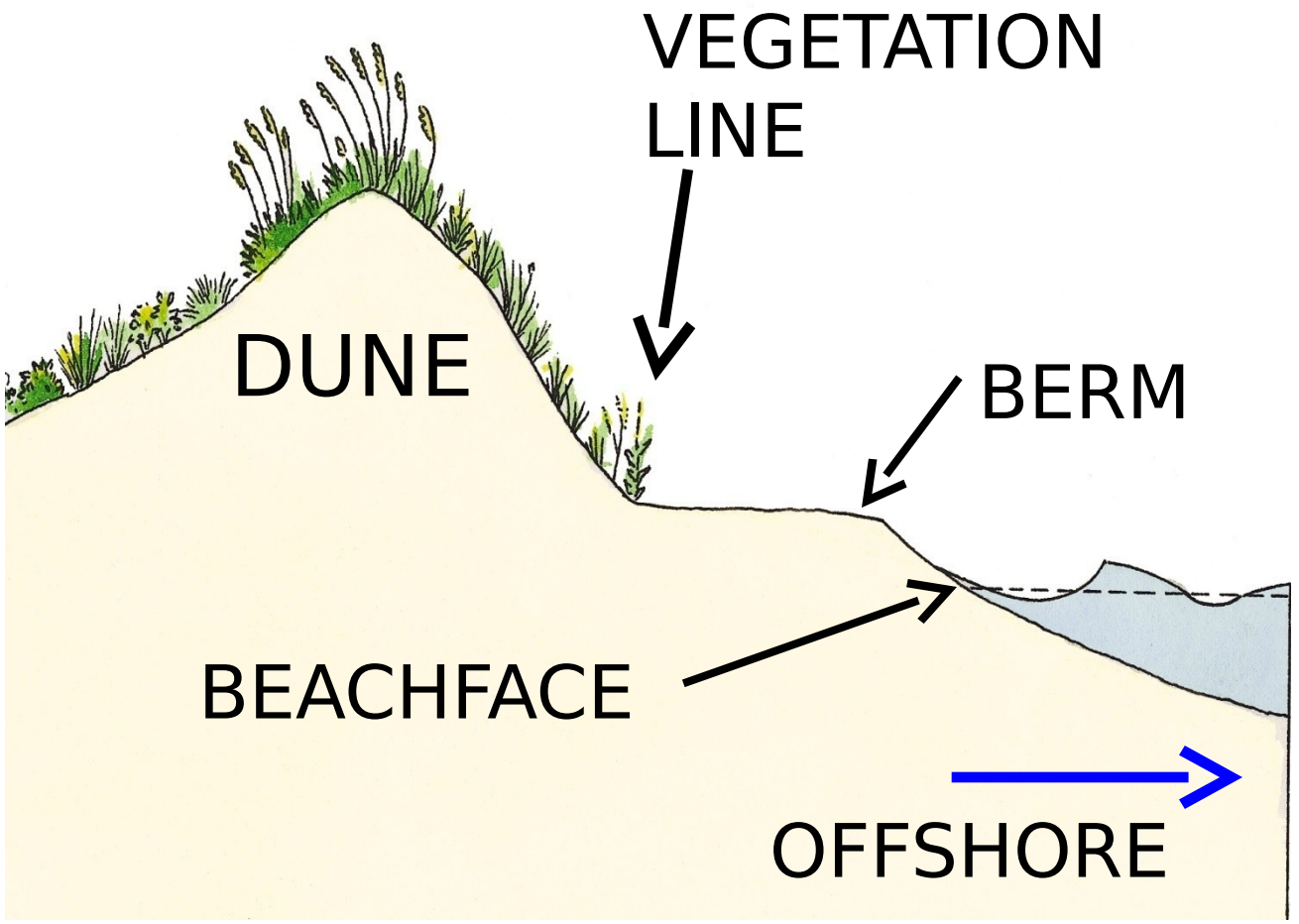
Storm Surge



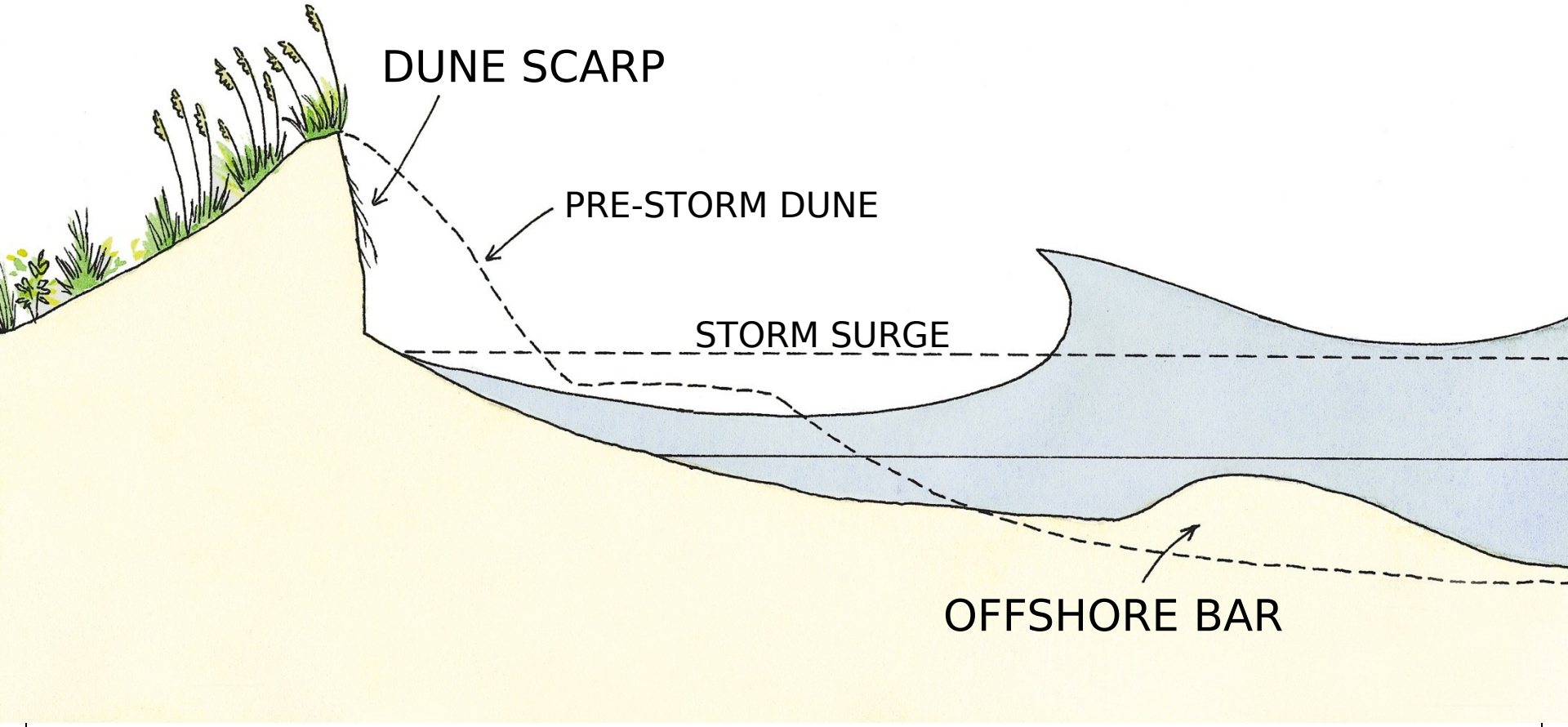


Wave breaks: Wave Height ~ Depth

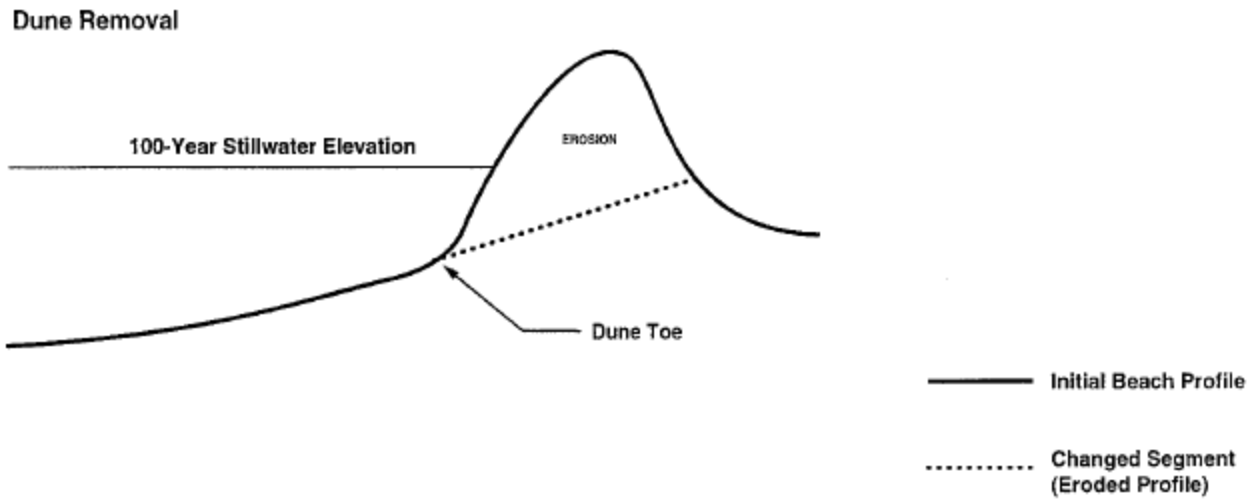
DEFINITIONS



STORM EFFECTS

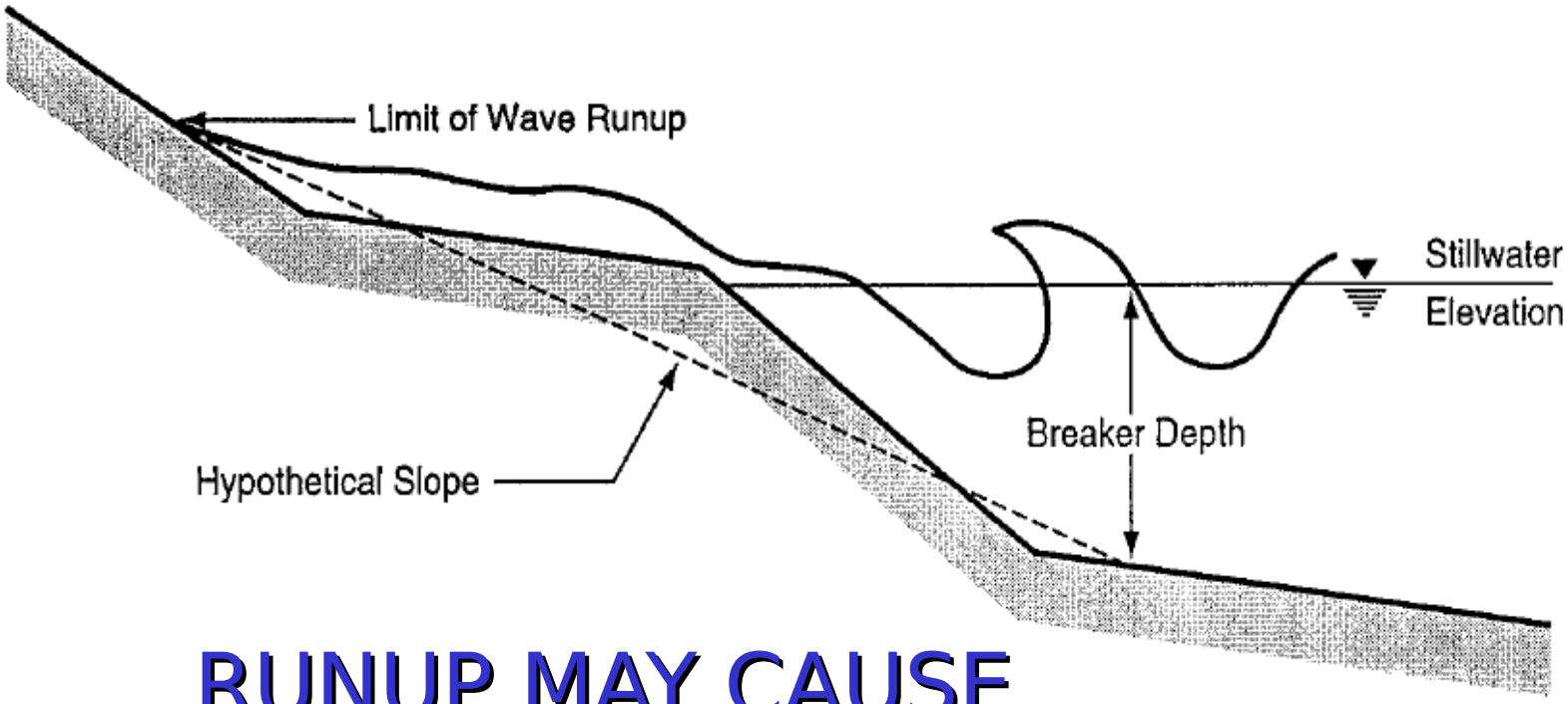


540 sq ft RULE



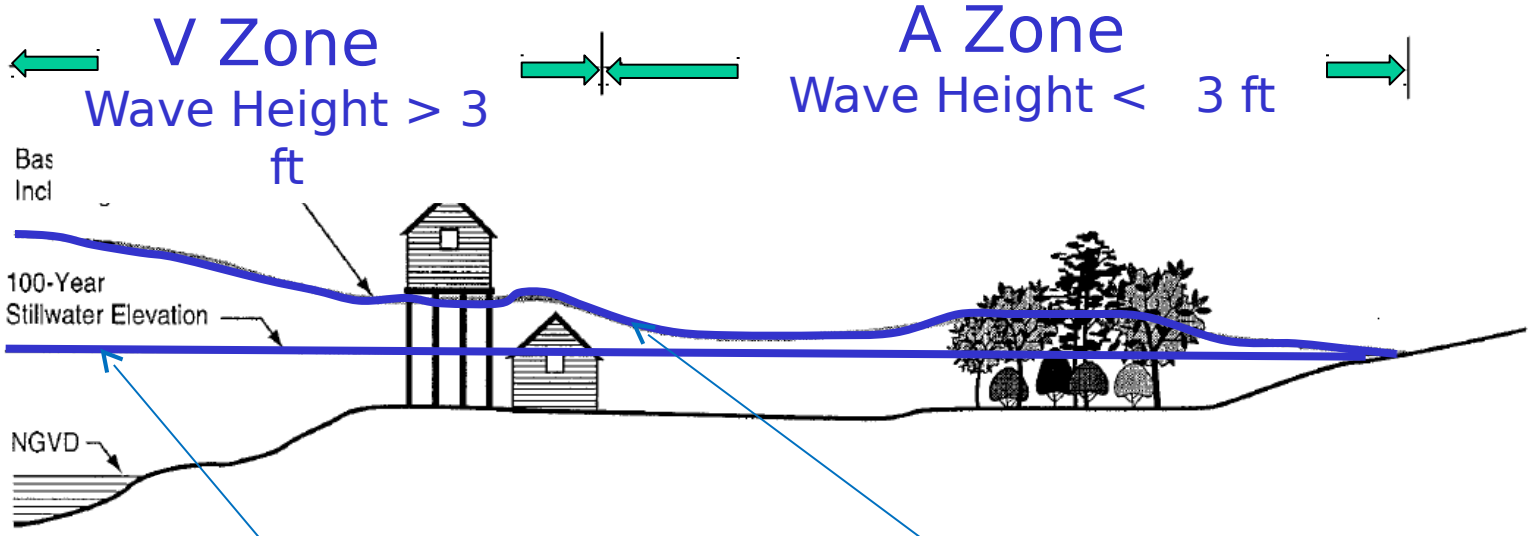
Eliminates the dune if volume of sand above stillwater elevation is insufficient to impede waves

WAVE RUNUP



RUNUP MAY CAUSE OVERTOPPING

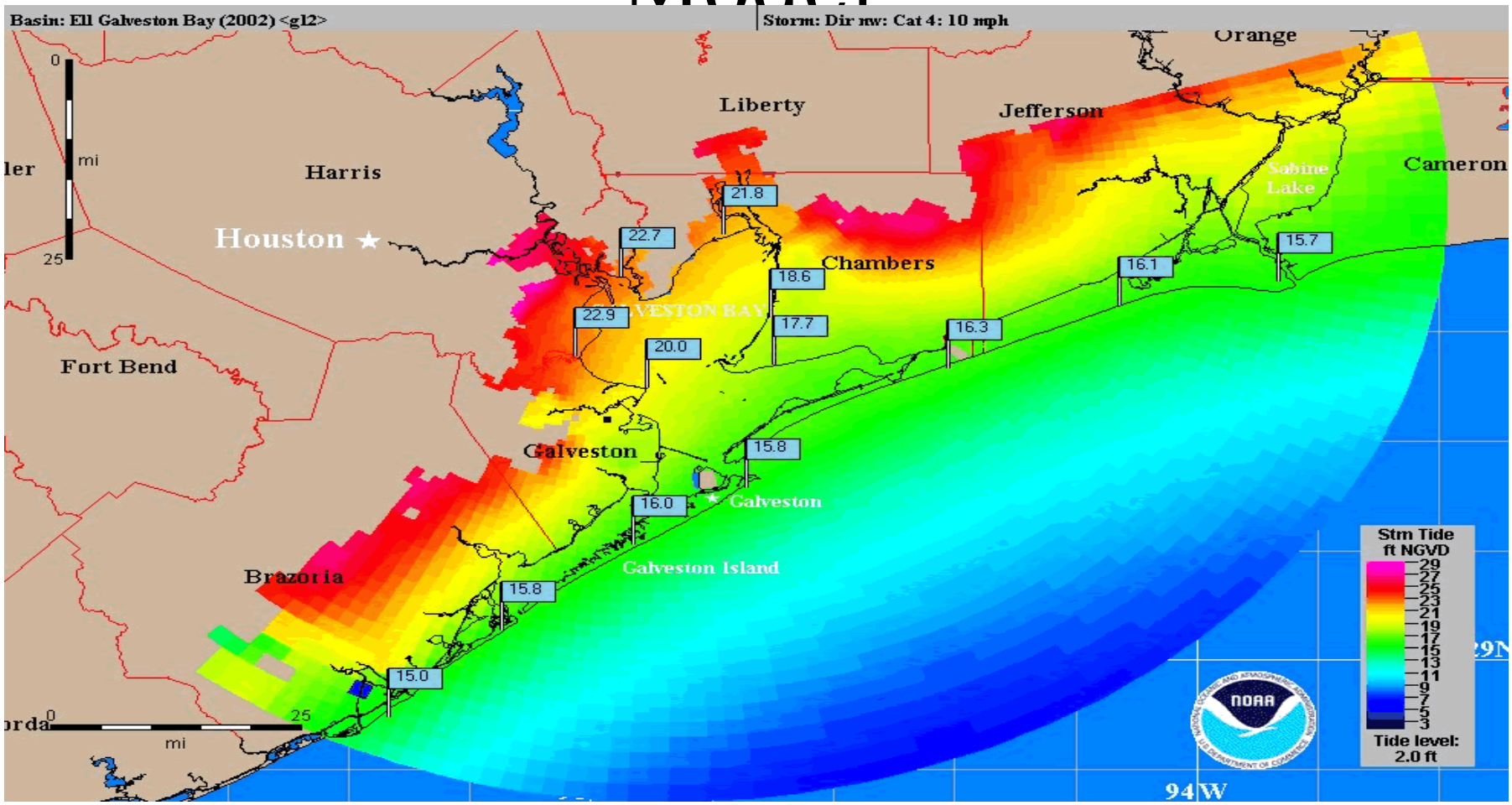
Coastal Flood Elevations



100-year Stillwater Elevation (offshore conditions)

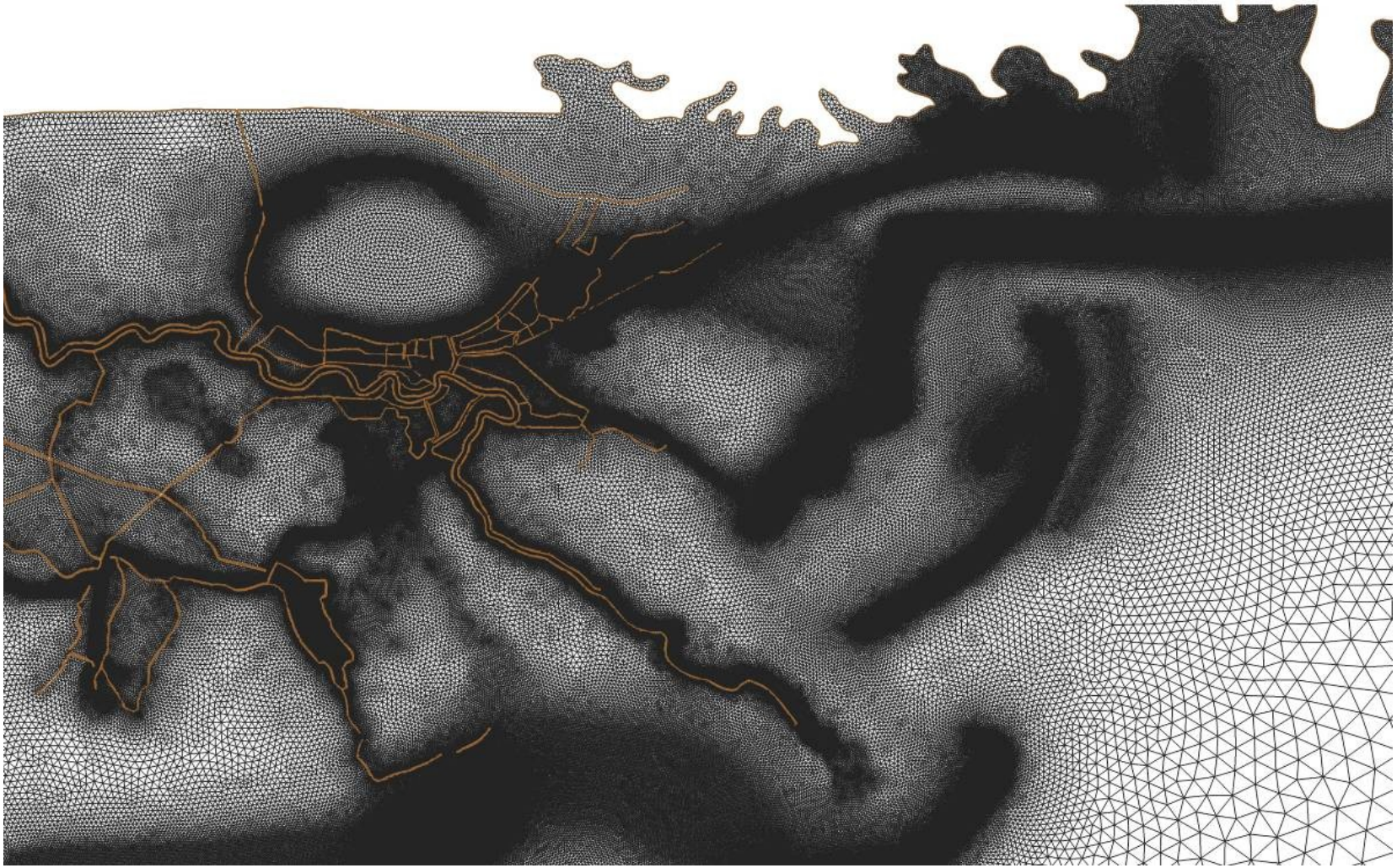
Base Flood Elevation (onshore conditions)

SLOSH – NOAA Storm Surge Model



Storm: Cat. 4 moving NW at 10mph

ADCIRC (Advanced CIRCulation) Model

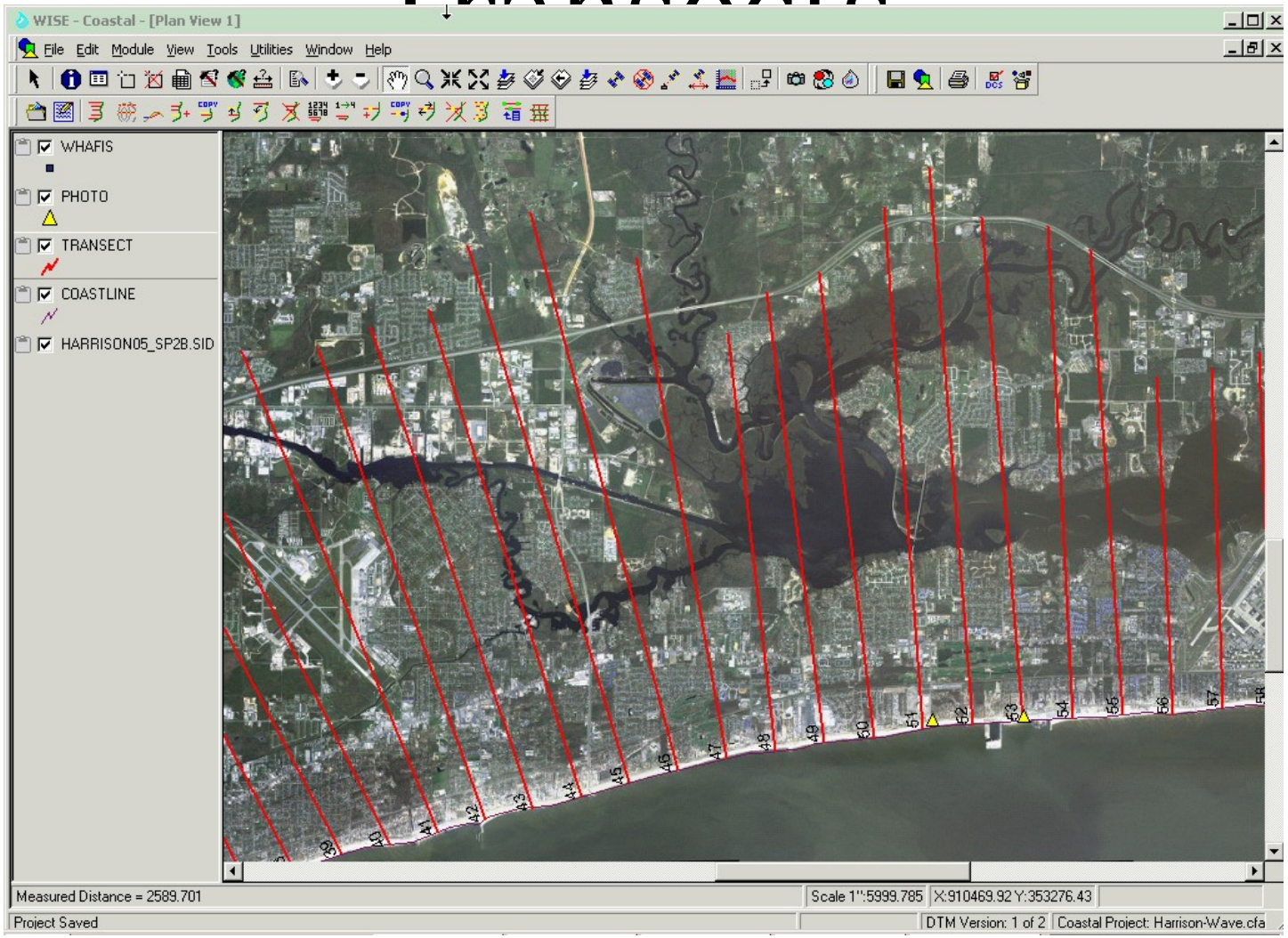


Finite element model, used by USACE for Gulf Coast studies

Storm Simulation

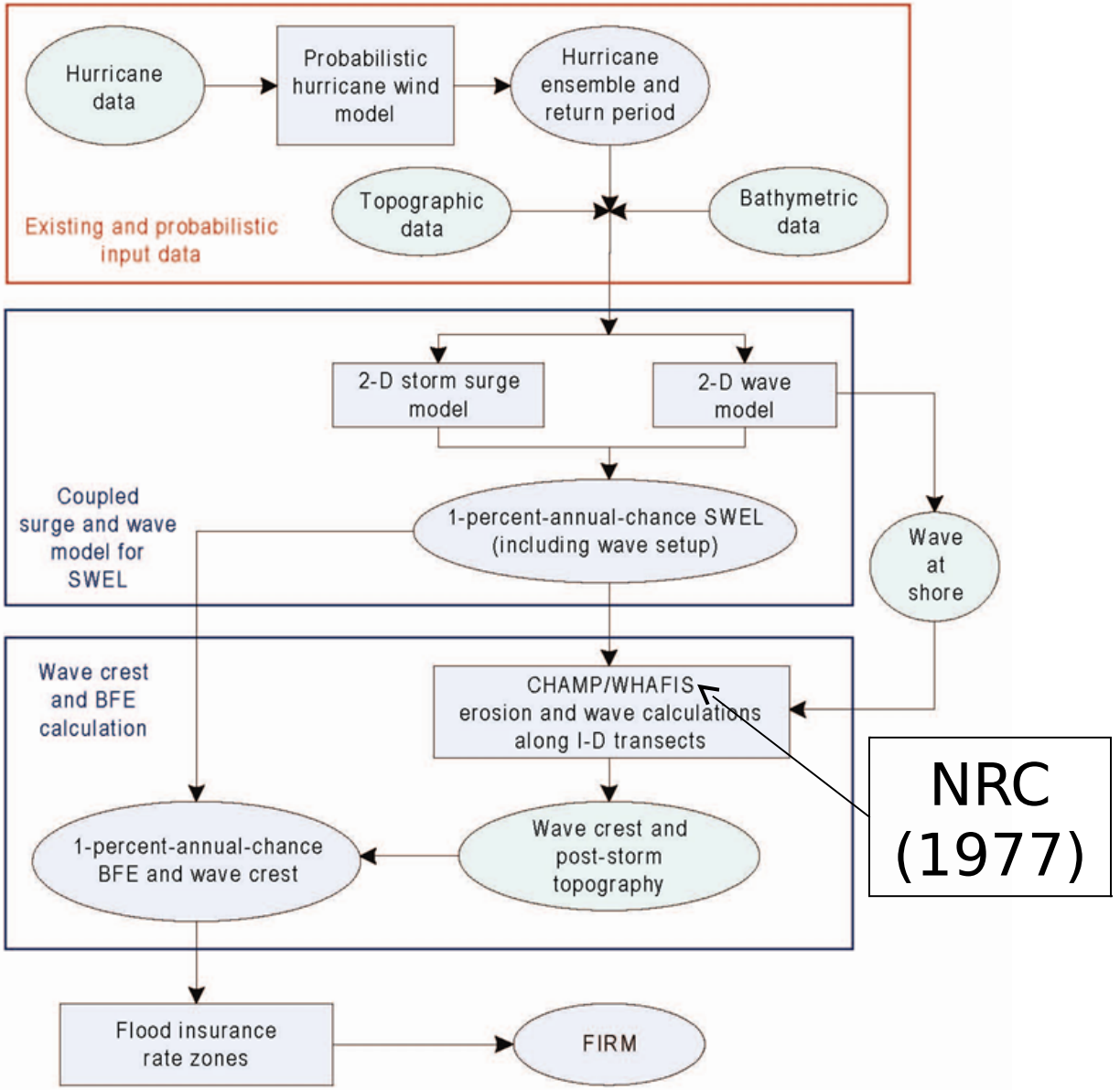
- Storm surge is affected by wind, atm pressure, bathymetry, tide, wave, topography, etc.
- Tides in the Gulf of Mexico are 2-3 ft in amplitude. Along the Atlantic coast, tides increase from 2-3 ft in FL to 20 ft in Canada.
- Waves are generally lower in Gulf Coast due to gentler slope.
- Factors affecting accuracy of storm surge simulation:
  - Input data (wind, bathymetry, topography, etc.)
  - Model dimensionality, domain, grid resolution
  - Model processes, parameterization, and coefficients
    - Wave-current interaction (2D, 3D, one-way, two-way)
    - Surge-tide interaction
    - Marshes, barrier islands, buildings, levees
    - Manning's n for bottom friction, air-sea drag coefficient
    - Precipitation and riverine flow
    - Erosion

Coastal Flood Mapping Transects



Current coastal flood mapping methodolog y

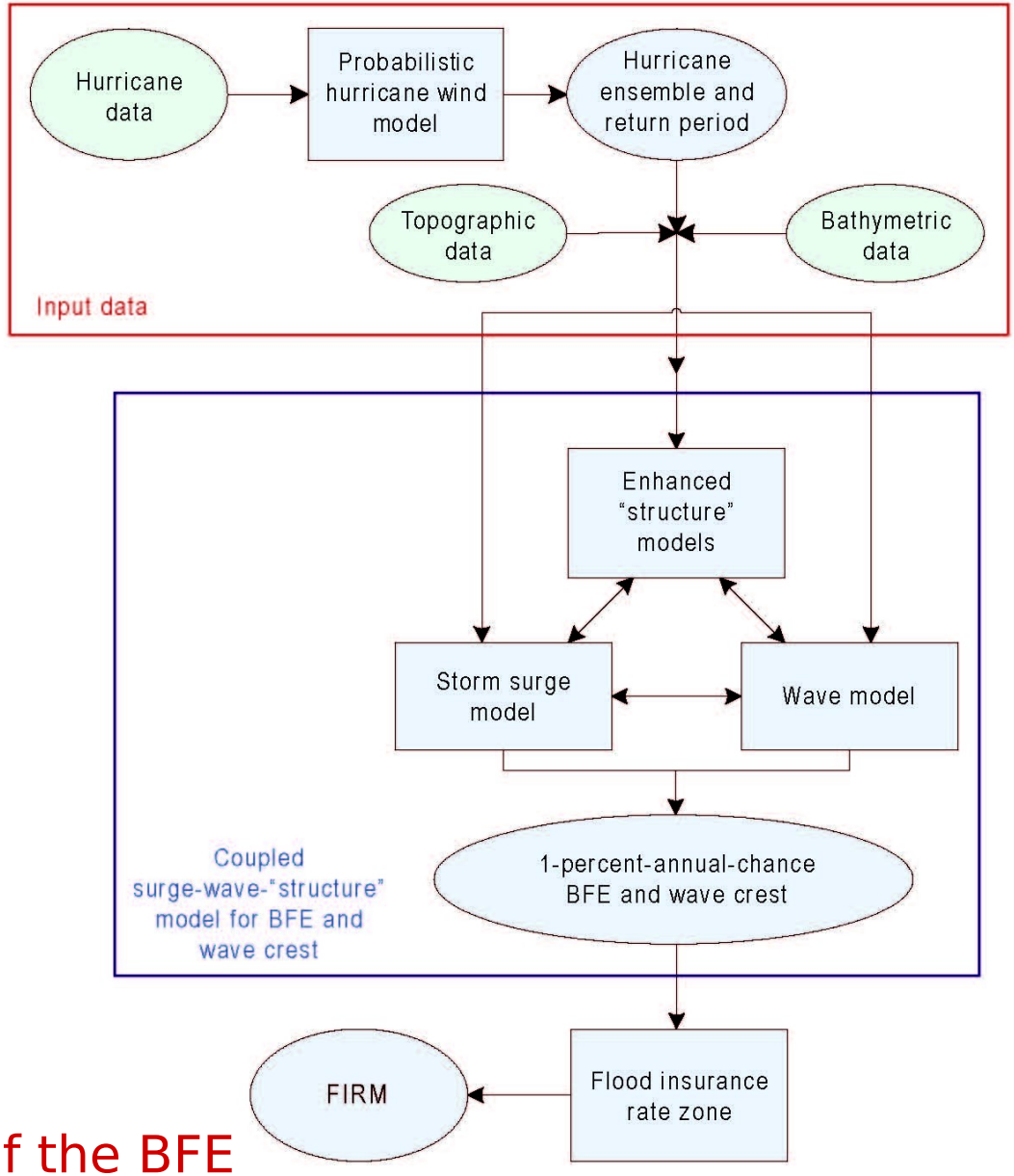
- Wave and erosion phenomen a are treated separately from the storm surge modeling



Proposed Coastal flood mapping methodology

Advances from academic research

- 1-D to 2-D and 3-D
- coupling process models
- additional processes e.g. erosion



To improve accuracy of the BFE

Coastal Bathymetric Data

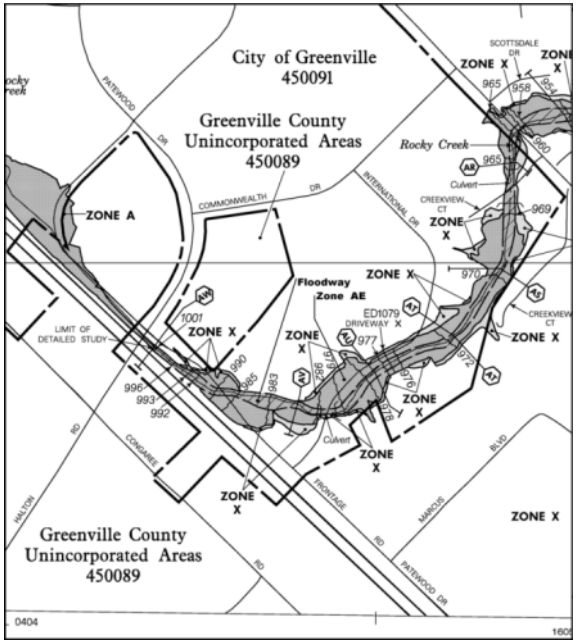
- Waves start to sense the sea floor when the depth < 40 ft
- Most critical zone for accurate bathymetric data is in the near-shore coastal environment and in coastal bays and inlets
- Barrier islands are important but difficult to deal with in storm surge simulation
- Model uncertainty >> bathymetric data uncertainty

Presentation Outline

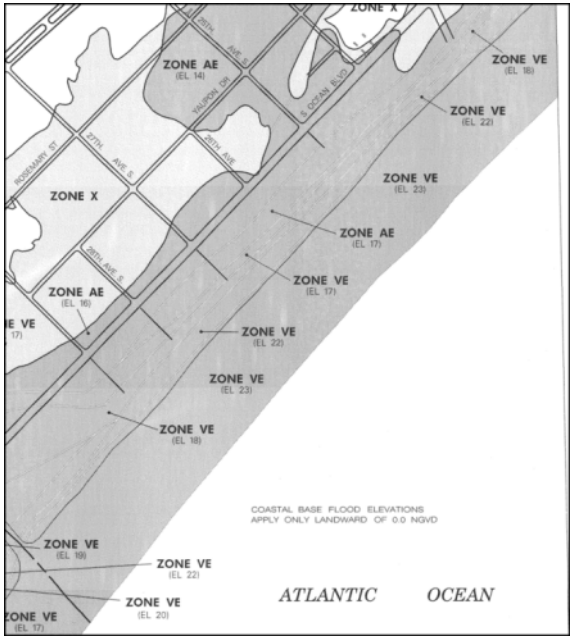
- Overview of Committee Charge
- Review of Elevation for Floodplain mapping study
- Mapping the Zone Report Chapters
  - 1-3 Overview of flood mapping and terrain data
  - 4-5 Inland and Coastal flood mapping
- *Overarching Findings*

Flood Maps

Riverine



Coastal

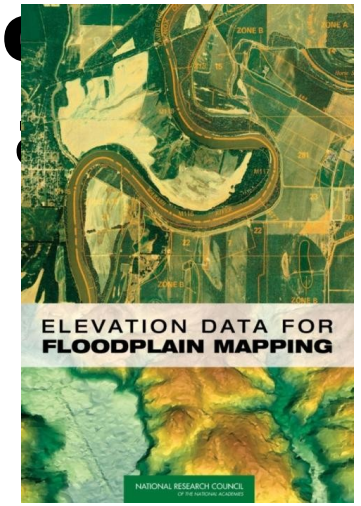


Two very different flood modeling and mapping problems

Overarching Finding

1. Topographic data is the most important factor in determining water surface elevations, base flood elevation, and the extent of flooding, and thus the acc
of flood maps in riverine

This finding reinforced the conclusion of the earlier study

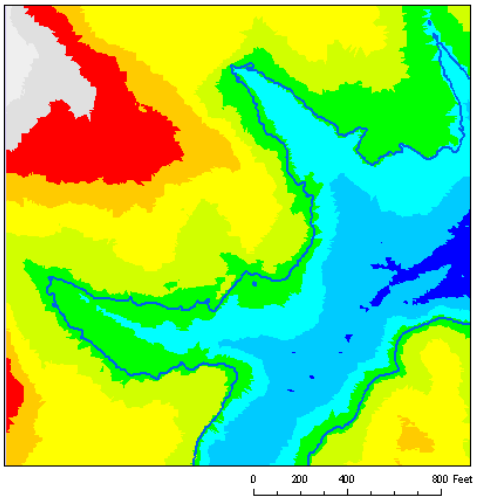


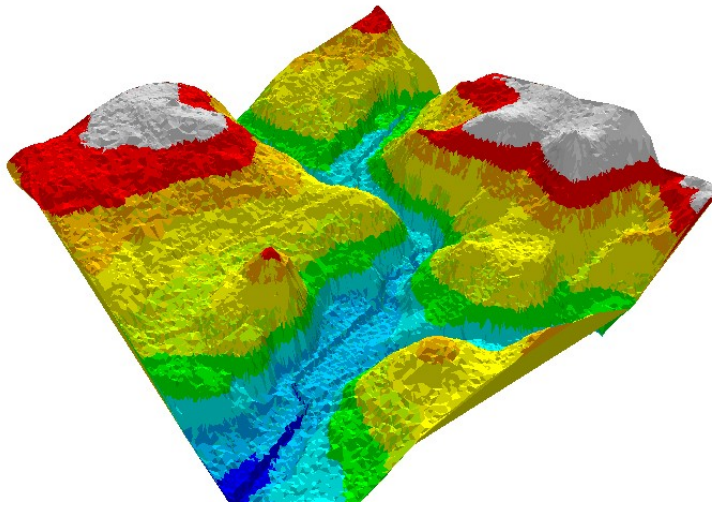
Overarching Finding

2. Coastal flood maps can be improved significantly through use of coupled two-dimensional storm surge and wave models and improved process models for dealing with erosion and other processes

Overarching Finding

3. Flood maps with base flood elevations yield greater net benefits than flood maps without such elevations





Bottom Line

- Riverine Flooding
  - Elevation, elevation, elevation
- Coastal Flooding
  - Inundation process is complex
- Economic Analysis
  - Base flood elevations are worth the cost
- Risk Mapping
  - Better maps can provide good risk information